Final Report
Cooperative Agreement Number 42-804

CHARACTERIZATION OF BLACK OAK DECLINE AND ASSOCIATED CYNIPID GALL WASP ON NEW YORK'S LONG ISLAND

June 1999

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State and Private Forestry
Durham, NH

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ABSTRACT

Severe dieback on black oak trees, *Quercus velutina* Lamarck, on New York's Long Island was first apparent in the late 1980s. A twig-galling cynipid wasp and a fungal canker were associated with crown dieback. Symptoms were more severe in residential and urban park ecotypes than forested areas. Symptoms included swollen twigs, gnarled branches, crown dieback, and fungal cankers. Residual gall wasp populations from within twigs were compared among ecotypes and three crown categories (low, moderate, and severe dieback). Insect populations were significantly greater on trees with severe crown dieback in residential areas and urban parks. In forested areas, insect numbers were similar among crown categories. Radial growth differed significantly between trees with severe and low crown dieback prior to 1980 in one residential area, one forested area, and both urban parks. High numbers of gall wasps associated with urban areas, combined with previous stresses, are likely to have contributed to the greater severity of decline in parks and residential areas than forested areas. Management of this decline syndrome is best accomplished by maintaining tree health before and during periods of stress, and removing affected trees that pose a threat to lives and property.

INTRODUCTION

In the mid-1980s, black oak trees (*Quercus velutina* Lamarck) across New York's Long Island were exhibiting crown dieback. In addition to crown dieback, other symptoms including swollen twigs, fungal twig cankers, unusually large leaves, and epicormic branching were apparent. Initial investigations by the Suffolk County Cooperative Extension Service identified two organisms associated with the dieback: a cynipid gall wasp (*Bassettia ceropteroides* Bassett) and a fungal canker belonging to the genus *Botryosphaeria*. *Botryosphaeria* spp. is well studied and generally produces dieback as an opportunistic secondary organism, but little is known about the biology of *B. ceropteroides*.

The dieback and decline of black oak had aroused significant public and private scrutiny by 1994. The public's growing concern for the health of this tree species on Long Island was reflected in articles published by the New York Times (Barron 1981, Fullam 1994), USDA Forest Service, State and Private Forestry (Anonymous 1994), and several regional papers. Despite a wide variety of attempts by arborists and landowners to reduce the severity of symptoms on black oak, no immediate solutions were found. Concern over the future of this tree species on Long Island culminated in a contract between the USDA Forest Service and State University of New York College of Environmental Science and Forestry to conduct the research which is documented in this thesis.

Declines among *Quercus* sp. have historically been associated with defoliation events, abiotic events such as drought and frost, and secondary insects, particularly the two-lined chestnut borer, *Agrilus bilineatus* (Weber). The causality of wide-scale dieback of oak, reported as early as the 1900s in the United States and later in the 1930s and 1940s, was attributed to a variety of conditions and organisms. In the late 1960s dieback of oaks in

forests of eastern Pennsylvania was recognized as a decline, in which long term stresses contributed to symptoms appearing later in the tree's life. The widespread nature of this decline impacted the forest industry considerably, with losses of sawtimber ranging from 3-7,000 board feet per acre (17-41 cubic meters per hectare) (Nichols 1968).

In urban areas, decline diseases such as the one on black oak described in this study, are often overshadowed by more devastating and rapidly spreading pathogenic diseases on other tree species, like Dutch elm disease, elm yellows, and chestnut blight. However, the simultaneous maturation of large cohorts of oaks in urban areas has generated concern for their susceptibility to a variety of pests and abiotic conditions. The demise of Norway maple in urban areas, described by Apple and Manion (1986), represents a recent decline disease affecting a population of trees that dominate an urban landscape. Thus, concerns that black oak, a common middle-aged tree on Long Island, may be threatened are not without precedent.

In summer 1994 the extent and severity of crown dieback and twig deformities associated with the gall wasp and fungal canker on black oak were surveyed on Long Island. Trees were surveyed in three ecotypes: residential areas, urban parks, and forested areas. In 1995, an intensive study investigating the relationships between the cynipids and their tree hosts was undertaken. By 1996 the symptoms had subsided across the Long Island in all but a few isolated locations. Tree mortality attributed to the gall wasp was difficult to assess because many urban trees with severe dieback were removed premortem. Trees that survived despite heavy gall wasp attack may become susceptible to dieback from future outbreaks of the same gall wasp or other secondary pests. The presence of overmature trees in urban

areas, coupled with periodic stresses, ensure that various cycles of decline will appear again in the future.

METHODS

SURVEY TO DETERMINE EXTENT AND SEVERITY OF DECLINE ACROSS LONG ISLAND.

A systematic approach was used to assess the geographic extent and severity of black oak decline on Long Island and the surrounding areas. This approach was designed to quantitatively evaluate the symptoms related to the reported decline in Nassau and Suffolk Counties. The names of villages and parks where surveys were conducted are listed in A-Table 2. Surveys were conducted in three different ecotypes: (1) residential areas, (2) urban parks, and (3) forested areas. A detailed description of the ecotypes is provided in Appendix I. The taxonomic soil association for each plot in residential areas, urban parks, and forested areas was determined from USDA Soil Survey maps for Nassau and Suffolk Counties (Warner et al. 1975, Wulforst 1987). The approximate positions of soil associations are shown in Figure 1, and a description of each is provided in Table 1. A description of the major soil series is provided in A-Table 1.

Extensive surveys were conducted in two areas, Queens County (eastern borough of New York City) and southern Connecticut, because of their proximity to Long Island. Details and findings of these surveys are described in Appendix I.

Residential Areas. In summer 1994, seven equidistant transect lines, approximately 15 kilometers apart, running north-south were drawn on a map across Nassau and Suffolk Counties. Transects were surveyed by driving on the nearest secondary roads to the transect lines and a plot of ten black oak trees was established approximately every 10 km. Plot locations are shown in A-Figure 1. Each plot consisted of a group of the "ten nearest"

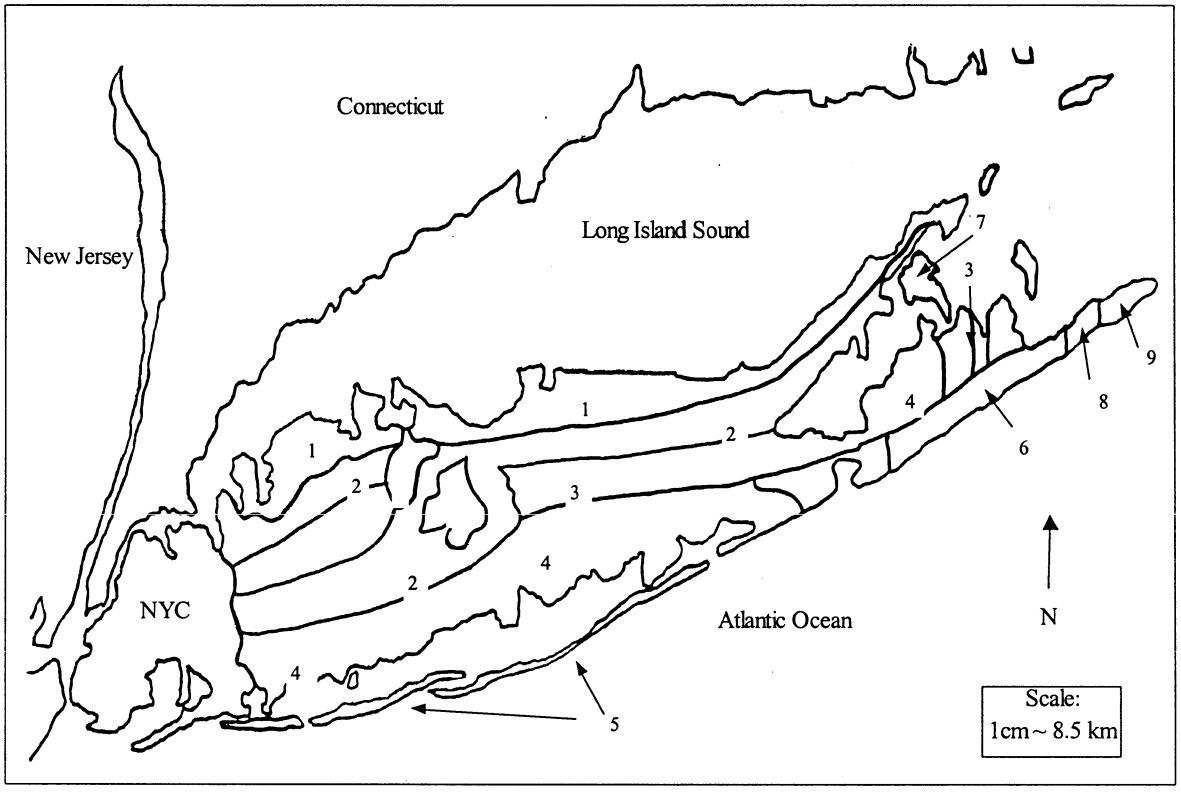


FIGURE 1. Soil associations of New York's Long Island (drawn from Warner et al. 1975). Descriptions for each association are provided in Table 1.

TABLE 1. Soil associations of New York's Long Island. Numbers correspond to Figure 1. Texture refers to surface soil texture. Soil descriptions are taken from Suffolk County Soil Survey. (Warner et al. 1975)

Number	Soil Association Unit	General Description
1	Carver-Plymouth-Riverhead	Deep, rolling, excessively- and well-drained, coarse- and moderately-coarse-textured soils on moraines.
2	Haven-Riverhead	Deep, nearly level to gently sloping, well-drained, medium- and moderately coarse-textured soils on outwash plains.
3	Plymouth-Carver, rolling and hilly	Deep, excessively-drained, coarse-textured soils on moraines.
4	Riverhead-Plymouth-Carver	Deep, nearly level to gently sloping, well- and excessively-drained, moderately-coarse and coarse-textured soils on the southern outwash plain.
5	Dune Land-Tidal Marsh-Beaches	Sand dunes, tidal marshes, and beaches of the barrier beach and south shore.
6	Bridgehampton-Haven	Deep, nearly level to gently sloping, well- to moderately-well-drained, medium-textured soils on moraines.
7	Montauk-Haven-Riverhead	Deep, nearly level to strongly sloping, well- to moderately well-drained, moderately-coarse and medium-textured soils on moraines.
8	Montauk, sandy variant-Plymouth	Deep, rolling and hilly, excessively drained, coarse-textured soils on moraines.
9	Montauk-Montauk, sandy variant-Bridgehampton	Deep, rolling and hilly, excessively- and moderately well-drained to well-drained, medium- to coarse-textured soils on moraines.
10	Plymouth-Carver, nearly level and undulating	Deep, excessively-drained, coarse-textured soils on outwash plains.

accessible black oak trees visible from the road. In this way some plots contained ten trees very close together, others included trees over a linear area of up to about 400 meters. Two to four plots per transect were established. Twenty-one plots were identified in residential areas and a total of 210 trees were surveyed. Five trees were removed from the survey later due to mis-identification. Most trees occurred on lawns within 10 meters of sidewalk, driveway, or pavement.

For each tree, the diameter at breast height outside the bark (dbh) was recorded with a diameter tape and tree height was estimated with a clinometer. Percent crown dieback was assessed using methods described in Millers et al. (1991) and Cooke et al. (1995). Estimates were based primarily on the percentage of dead distal, terminal branch tips. Independent assessments of crown dieback and tree height were made by two technicians for each tree and averaged. Each tree was categorized according to its dieback level: low dieback, if dieback was less than 20 %; moderate, if dieback was between 20-50 %; and severe, if dieback was greater than 50 %. Each tree was examined for damage on the bole or crown. This data is shown in A-Table 3.

Ten terminal branches from the perimeter of each tree were observed with binoculars. Since twig galls and cankers were observed throughout the tree crown, the ten branches selected for observation were taken from as many areas of the crown as possible. On each terminal branch, the presence or absence of twig galls, fungal cankers, and tip dieback were noted. Twig galls appeared as localized swellings on second year, third year and older growth. Cankers appeared as elongate seams on terminal branches, and varied from small localized knots to elongated seams spanning many years of growth. The percentage of these

branches having any galls (% galling), cankers (% cankering), or tip dieback (% tip dieback) was used to estimate relative severity on each tree.

Urban Parks. In the summer of 1994, ten black oak trees were observed in each of six major state parks on Long Island , except at one park where only 3 black oaks were located. Plot locations are shown in A-Figure 2. A total of 53 trees were surveyed at sites with camping facilities, picnic grounds, or other areas exposed mainly to pedestrian traffic. In general, all ten trees were within 100 meters of each other. Each tree was examined and measured as previously described.

Forested Areas. Thirteen areas in State and County forests on Long Island were surveyed during summer 1994. Plot locations are shown in A-Figure 3. In each area, three .04 hectare circular plots were established at least 45 meters from a non-paved road. In Rocky Point forest, six plots were established because of the park's large size. A total of 135 trees were surveyed in forested areas.

Within each circular plot, the dbh and species of all trees greater than 5 cm dbh were recorded. Tree species and their basal areas per hectare are listed in A-Tables 4 and 5. All black oak trees within each plot were examined and measured as previously described.

In summer 1996, all plots were re-vistited. For each tree, % crown dieback was estimated. All trees in urban parks were assessed, but only 178 trees in residential areas and 40 in forested areas were found because trees were missing or difficult to locate.

Statistical Analyses. Means for tree height, diameter, % crown dieback, % galling, and % cankering were calculated for each ecotype. Means for each variable were also determined for the soil association classification that corresponded with individual plots. Comparisons among ecotypes and soil associations were performed using analysis of

variance, general linear models procedure by Statistica computer software (Statsoft, Inc. 1995). Statistical significance was evaluated at $p < 0.05$. When significant differences were found, mean separations were performed using Tukey's Honest Significant test for Unequal N (Spjotvoll and Stoline 1973). Variances were evaluated for homogeneity using Levene's test (Milliken and Johnson 1984). Data transformations were performed when Levene's test was violated, and are indicated on the tables. Variables for which variance homogeneity could not be achieved were analyzed in their untransformed condition and are indicated as such in various Tables and Figures. Means for individual plots and comparisons among them are shown in A-Tables 6-8. Correlations were performed among % crown dieback, % galling, % cankering, and % tip dieback variables using Pearson Correlation. Urban parks and residential areas were combined because of similar tree form (Table 3, Tree height and dbh), and because there was no persistent leaf layer at either ecotype. The conditions in urban parks and residential areas were similar, as most trees were subjected to the effects of soil compaction, mechanical bole injuries, and seasonal leaf removal. Soils in forested areas were relatively undisturbed.

PROBABLE ROLES OF TREE VIGOR, CYNIPID GALL WASP AND FUNGAL CANKER.

Site Selection. An intensive survey was conducted in summer 1995 to study the relationship of decline symptoms with site and tree characteristics. No trees that were studied in 1994 were included in the 1995 study. Two locations in Suffolk County representing different soil associations were chosen for intensive study. One site was located on the "North Shore", the other on the "South Shore" (Figure 2). Ninety trees were chosen at each location, distributed among three ecotypes (residential areas, urban parks, and forested areas). In each ecotype, approximtely ten trees were chosen without regard to size from each

of three crown categories: low dieback (<20 % crown dieback), moderate dieback (20-50 % crown dieback), and severe dieback (>50 % crown dieback) (Table 2). The % crown dieback, tree size and characteristics of the microsite around each tree were recorded as reported in the previous section, "Methods: Survey to Determine Extent and Severity of Decline Across Long Island."

One terminal branch, at least one meter long, was removed from each tree with pole pruners from the lower-south portion of the canopy, or the nearest accessible side. Branch samples were placed in plastic bags, and refrigerated (4° C) until they could be processed. Annual twig growth, measured as the distance between twig nodes, was measured on the most dominant, living branchlet. Using pruning shears, each twig, from which nodes were measured, was dissected by making cross sectional cuts at approximately 1 mm from the terminal bud down to the base of the twig sample. All gall wasps were removed from gall chambers exposed during the twig dissections, and stored in alcohol. The growth year in which the wasp resided was determined based on the position of the gall within the cross-sectional growth rings and external twig nodes. Both empty galls from which cynipids apparently emerged, and galls containing entombed cynipids, were counted.

Tree Ring Analysis for Age and Growth. One increment core, taken to the pith at breast height, was obtained from each tree. Ring widths were measured for all but current growth using a Unislide Tree Ring Measuring System equipped with the Acu-Rite sliding scale and linear encoder interfaced with the quick-Check QC-1000 digital measuring device (Velmex, Inc., East Bloomfield NY). Measurements were taken at a precision of 0.001 mm.

Basal area increment was calculated for each growth ring. Samples from the same site and ecotype were cross-dated graphically by comparing basal area fluctuations over the past

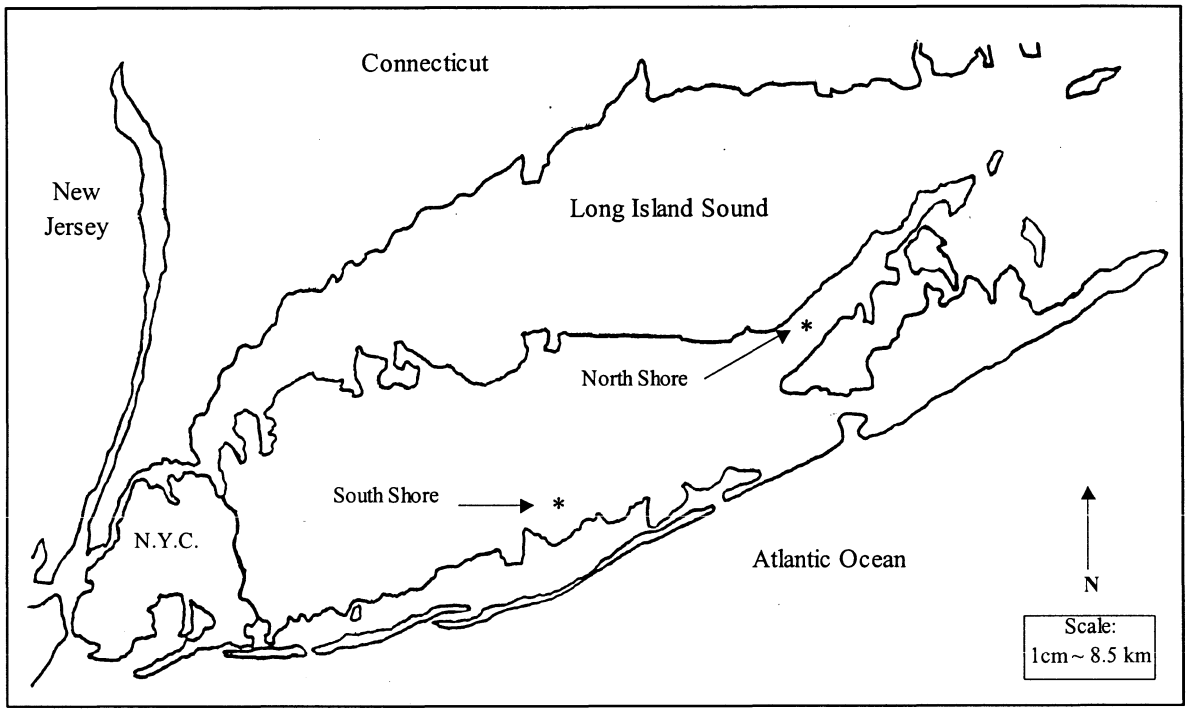


FIGURE 2. Location of North and South Shore sites for 1995 study.

TABLE 2. Experimental design for study conducted summer 1995. The number of trees sampled per ecotype and crown category are shown.

	North Shore			South Shore		
Crown Dieback	Urban Park	Residential Area	Forested Area	Urban Park	Residential Area	Forested Area
Low	10	10	9	10	10	9
Moderate	12	7	10	10	11	10
Severe	8	10	10	10	9	10

25 years (Fritts 1976). Means were calculated for five-year intervals (1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994) spanning 25 years of growth.

Increment cores were also obtained from ten co-dominant white oak from forested plots at each site to provide a comparison control for the growth analysis. White oak has similar site index to black oak (Carmean 1965) and is not a known host for *B. ceropteroides.* Basal area was calculated from annual rings, and cross-dated to others at the same location using the methods described earlier. Rainfall history was obtained from weather stations near the North and South Shore locations (Northeastern Regional Climate Center, Ithaca NY). Annual basal area increment was compared among sampled black oak trees for the 25 year period, 1970-1994.

Statistical Analyses. A 3 x 3 factorial analysis of variance, in a completely randomized design, was used to compare main and simple effects of ecotype and crown category separately for the two sites. Tree height, diameter, mean number of galls per twig, and mean annual twig lengths were the variables tested. Ecotype and crown main effects were examined by the Fisher's Protected Least Significant Differences Test (FPLSD) (Steel and Torrie 1980). This test was used instead of Tukey's HSD (in Methods I) because FPLSD offers the least protection against a Type I error (Statsoft 1995). Greater detection of differences was desirable due to the small sample sizes. All significance was tested at $p < 0.05$. Differences among crown categories within ecotypes were evaluated using FPLSD as well. Nodes prior to 1990 were difficult to distinguish on many twigs, therefore statistical analyses were performed only on the most recent six years of growth (1990-1995). FPLSD tests were performed on log-transformed means to compare periodic growth among crown categories.

RESULTS

EXTENT AND SEVERITY OF DECLINE ON LONG ISLAND.

Ecotype Comparisons. Observations of percent crown dieback, twig galling, and twig cankering were compared in a frequency table, and five severity classes were designated. Percent crown dieback for the majority of trees (approximately 80 %), regardless of ecotype, was less than 20 % (Figure 3 A). No significant differences among ecotypes for % crown dieback were revealed by ANOVA (Table 3).

Percent twig galling varied considerably among severity classes, although the majority of trees in urban parks (60 %) were represented in the highest class (80-100 %) (Figure 3. B). This contrasted with forested areas where only 10 % of trees surveyed contained between 80-100 % twig galls. No significant differences for % twig galls were revealed by ANOVA (Table 3).

Percent twig cankering was generally low, and most observations were represented in the lowest two severity classes (0-19 %, and 20-39 %). Twenty percent of trees in residential areas, and 40 % in forested areas had fewer than 20 % twig cankering (Figure 3.C).

For both tree height and diameter, significant differences were observed among ecotypes. In urban parks and residential areas tree height and diameter were significantly greater than in forested areas (Table 3). In residential areas, means were similar to urban parks but significantly greater than forested areas.

Crown dieback in 1996, two years after the initial survey was performed, was not substantially different from 1994, although 30 % of trees in residential areas, 38 % in urban parks, and 24 % in forested areas showed improved percent crown dieback (Figure 4). Percent crown dieback decreased in less than 1 % of all trees observed in 1996. The percent

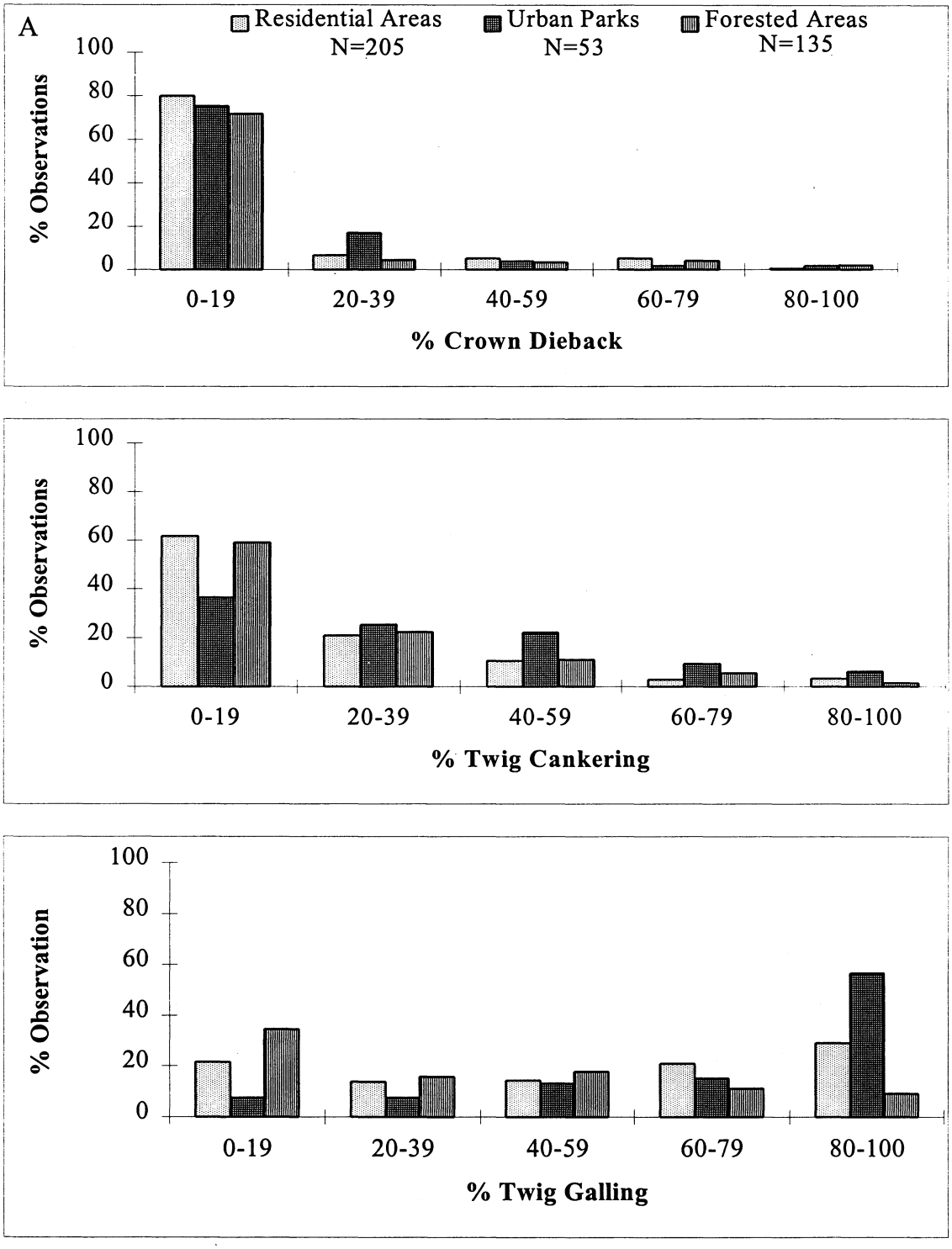


FIGURE 3. The percent of observations among severity classes by ecotype.

TABLE 3. Mean ± SD tree characteristics by ecotype. Means within a column followed by different letters are significantly different ($p < 0.05$), separated by Tukey's HS D Method.

Ecotype	Tree Height (m) [a]		Tree Diameter (cm) [b]		% Crown Dieback		%Twig Galling [c]		% Twig Cankering		N
Urban Parks	**17.4 ± 3.7**	**a**	**54.9 ± 23.7**	**a**	19 ± 16	a	**77 ± 26**	**a**	**39 ± 25**	**a**	53
Residential Areas	16.0 ± 4.4	ab	51.6 ± 19.6	a	18 ± 19	a	59 ± 33	a	25 ± 23	b	205
Forested Areas	14.7 ± 5.5	b	28.2 ± 31.3	b	**20 ± 21**	**a**	37 ± 32	a	26 ± 23	b	135

Note: Bold indicates largest value within each column.

[a] Tree Height remains heteroscedastic.

[b] Tree Diameter was square-root transformed for statistical analysis.

[c] Twig Galling was square-root transformed for statistical analysis.

crown dieback of the majority of trees, 64%, was similar to observations taken in 1994.

Residential Areas. Few significant differences were observed among soil associations across the residential areas (Table 4). However, for all three crown condition measures, soil association 4 (abbreviated S. A. 4) consistently had the largest percentage of trees with indicators of decline, S. A. 3, 8 and 9 with the smallest % of trees with indication of decline. Tree height and diameter were significantly different among soil associations, and were greater on the North Shore (S. A. 1 and 7) than on the South Shore and barrier islands (S. A. 4 and 5).

Urban Parks. Significant differences among soil associations were found for tree height and diameter only (Table 5). No significant differences among soil associations were found for percent crown dieback, galling, and cankering.

Forested Areas. Means for trees on various soil associations were significantly different for tree height and diameter. Tree height was significantly greater on S. A. 1 than on S. A. 4 (Table 6). No significant differences were detected among soil associations for percent crown dieback or percent galling. Percent twig cankering differed significantly between S. A. 2 and S. A. 3.

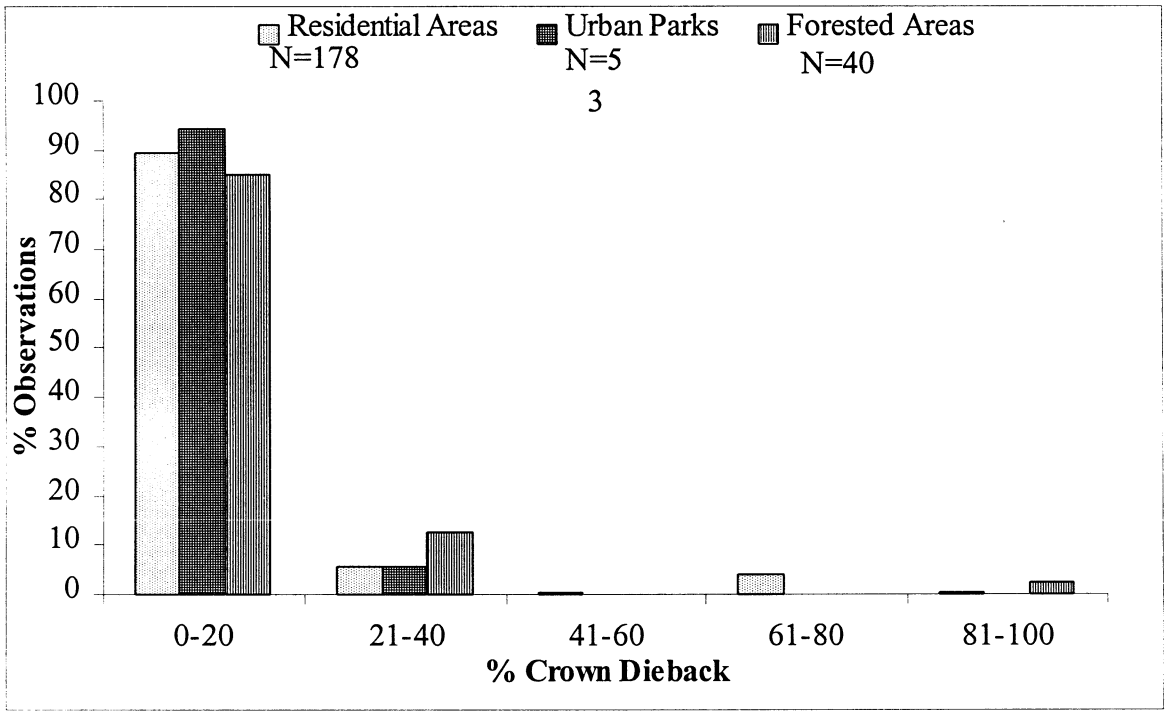


FIGURE 4. The percent of observations among severity classes for % crown dieback in 1996 by ecotype.

Table 4. Mean ±SD characteristics for trees in residential areas by soil association (see Figure 1 for soil association locations). Means within a column followed by different letters are significantly ($p < 0.05$) different, separated by Tukey's H.S.D. Method.

Soil Association	Tree Height (m) [a]			Tree Diameter (cm) [b]			% Crown Dieback [b]			% Twig Galling			% Twig Canker [c]			N
1	**19.6**	± **4.0**	**a**	59.5	± 15.9	a	14	± 12	a	59	± 33	ab	25	± 24	ab	40
7	19.4	± 3.9	a	**61.1**	± **16.1**	**a**	15	± 17	a	61	± 26	ab	21	± 21	ab	30
3	15.8	± 2.7	ab	41.5	± 10.7	ab	7	± 3	a	38	± 25	ab	15	± 12	ab	10
6	15.3	± 1.7	ab	34.2	± 10.6	bc	12	± 6	a	64	± 29	ab	15	± 14	ab	10
2	15.0	± 3.1	b	54.8	± 26.8	ab	16	± 14	a	62	± 31	ab	22	± 16	ab	28
8	14.7	± 3.0	b	50.0	± 21.2	ab	9	± 8	a	21	± 26	b	13	± 11	ab	9
4	14.5	± 3.0	b	46.8	± 14.9	ab	**28**	± **26**	**a**	**70**	± **31**	**a**	**39**	± **27**	**a**	60
9	13.8	± 3.0	b	49.1	± 10.2	ab	10	± 8	a	46	± 38	ab	5	± 7	b	9
5	7.6	± 1.7	c	26.5	± 18.9	c	21	± 19	a	46	± 43	ab	20	± 9	ab	10

Note: Bold indicates largest value within each column.

[a] Tree height was log-transformed for statistical analysis.

[b] %Crown dieback and tree diameter remain heteroscedastic.

[c] %Cankering was square root-transformed for statistical analysis.

Table 5. Mean ±SD characteristics for trees in urban parks by soil association (see Figure 1 for soil association locations). Means within a column followed by different letters are significantly ($p < 0.05$) different, separated by Tukey's H.S.D. Method.

Soil Association	Tree Height (m)			Tree Diameter (cm) [a]			% Crown Dieback			% Twig Galling			%Twig Cankering			N
3	**20.9**	± **2.4**	**a**	42.6	± 16.2	a	23.0	± 19.5	a	69	± 7.8	a	43	± 6.4	**a**	10
4	16.6	± 3.5	b	**57.6**	± **28.9**	**a**	18.0	± 13.5	a	78	± 11.4	a	36	± 11.4	a	30
7	15.1	± 1.9	b	51.7	± 6.1	a	**30.0**	± **25.4**	**a**	84	± 6.4	a	42	± 2.4	a	10
9	16.7	± 3.1	b	49.2	± 14.8	a	17.0	± 13.6	a	**86**	± **10.2**	**a**	**50**	± **5.8**	**a**	10

Note: Bold indicates largest value in each column.

[a] Tree Diameter remains heteroscedastic.

Table 6. Mean ± SD characteristics for trees in forested areas by soil association (See Figure 1 for soil association locations). Means within a column followed by different letters are significantly ($p<0.05$) different, separated by Tukey's H.S.D. Method.

Soil Association	Tree Height (m) [a]	Tree Diameter (cm)	% Crown Dieback [b]	% Twig Galling [a]	% Twig Cankering	N
1	**17.8 ± 6.0 a**	**36.6 ± 23.1 a**	12.5 ± 6 a	47 ± 32 a	25 ± 25 ab	34
2	15.9 ± 5.2 ab	22.1 ± 9.1 b	20.6 ± 18 a	**52 ± 30 a**	**37 ± 27 a**	31
3	13.6 ± 3.9 abc	24.4 ± 9.9 b	19.5 ± 23 a	29 ± 27 a	18 ± 19 b	32
4	10.0 ± 2.0 c	9.6 ± 2.5 b	26.7 ± 22 a	10 ± 14 a	25 ± 18 ab	12
7	11.9 ± 4.0 bc	16.0 ± 10.4 b	**36.7 ± 35 a**	32 ± 37 a	20 ± 21 ab	9
8	10.6 ± 6.3 bc	14.2 ± 7.1 b	24 ± 28 a	8 ± 13 a	20 ± 19 ab	5

Note: Bold indicates largest value in each column.

[a] Tree height and % twig galling were log-transformed for statistical analysis.

[b] % Crown dieback was square root transformed for statistical analysis.

Correlations between variables. Correlation coefficients among variables percent crown dieback, tree height, diameter, twig galling, and cankering were determined for urban parks and residential areas combined, and for forested trees alone. All correlations were weak, even when statistical significance was revealed. Percent crown dieback was negatively correlated with tree height ($r = -.17$ for residential areas and parks, $r = -0.37$ for forested areas) and very weakly with tree diameter ($r = -0.06$ for residential areas and parks, $r = -0.30$ for forested areas). There was a positive correlation between twig galling and crown dieback in residential areas and urban parks ($r = 0.37$), but the correlation was negative in forested areas ($r = -0.24$). Twig cankering was positively correlated with percent crown dieback in residential areas and urban parks, $r = 0.34$, but no correlation ($r = 0$) was observed in forested areas.

Probable Roles of Tree Vigor, Cynipid Gall Wasp and Fungal Canker.

Tree characteristics. On the North Shore, tree height was significantly greater in urban parks than in residential and forested areas, but no differences among ecotypes were observed on the South Shore (Table 7). In both locations, mean tree height did not differ among crown dieback categories. On the North Shore, tree diameters were significantly smaller in forested areas than residential areas or urban parks, but no significant differences were found among crown categories (Table 8). On the South Shore, significant differences were observed among crown categories and ecotypes. There, tree diameters were significantly greater on trees with severe crown dieback in comparison with trees having low crown dieback. Tree diameters were also greater among trees in residential areas than those in urban parks and forested areas.

On the North Shore, 60-70 % of trees in residential areas and forested areas were

between 40-80 years of age (Figure 5). The majority of trees in urban parks (approximately 60 %) were between 80-120 years. On the South Shore, the majority of trees in all ecotypes (55-100 %) ranged from 41-80 years, with less than 30 % of trees in any ecotype represented in the other 3 age classes (Figure 6).

Twig Dissections. The total number of twig galls per surveyed branch was averaged and compared among ecotypes and crown categories (Table 9). On the North Shore, insect numbers were similar among ecotypes and generally lower from trees with low dieback than from those with moderate or severe dieback. Significant differences among ecotypes occurred only on the South Shore, with trees from forested areas having fewer numbers of twig galls and, as found on the North Shore, fewer galls on trees with low dieback than on those with moderate or severe dieback.

Annual Gall Wasp Fluctuations. On both the North and South Shores, the number of twig galls per branch per year increased from 1990-1993 in residential areas and urban parks, and then declined sharply beginning in 1994 (Figures 7 and 8). In forested areas, the mean number of twig galls declined steadily across this time period but no sharp decline occurred (Figure 9).

The number of twig galls by year in residential areas differed significantly among crown categories for the North Shore only. The number of twig galls in trees with low dieback was significantly (t-test $p<0.05$) less than in trees with severe dieback for 3 out of the 6 years (1990, 1991 and 1993) (Figure 7). On the South Shore, no statistical differences occurred among crown categories for any year, although trees with low dieback generally had fewer galls than trees with moderate and severe dieback from 1990-1993. At

TABLE 7. Mean tree height (m) ± SD of black oak studied in 1995. Significant ($p < 0.05$) differences are indicated within a column by different letters. Separations were made using FPLSD. Significant differences for ecotype main effect, across the bottom row for North and South Shores, are indicated similarly.

Crown Dieback Severity	Residential Areas		Urban Parks		Forested Areas		Crown Category Mean	
	North Shore							
Low	14.9 ± 2.7	a	18.0 ± 2.7	a	14.6 ± 6.4	a	15.7 ± 4.3	a
Moderate	13.6 ± 2.9	a	16.7 ± 3.1	a	13.9 ± 6.2	a	14.7 ± 4.4	a
Severe	13.4 ± 3.0	a	17.2 ± 3.0	a	15.9 ± 5.0	a	15.5 ± 4.0	a
	Ecotype Means (crown dieback severity pooled)							
	14.1 ± 2.8	b	17.3 ± 2.9	a	14.8 ± 5.7	b		
	South Shore							
Low	13.3 ± 2.4	a	15.1 ± 2.1	a	12.6 ± 5.8	a	13.7 ± 3.8	a
Moderate	14.9 ± 1.6	a	14.1 ± 2.6	a	13.5 ± 4.2	a	14.2 ± 2.9	a
Severe	14.6 ± 1.3	a	13.9 ± 1.4	a	12.7 ± 2.6	a	13.7 ± 1.9	a
	Ecotype Means (crown dieback severity pooled)							
	14.3 ± 1.9	a	14.4 ± 2.1	a	12.9 ± 4.3	a		

TABLE 8. Mean tree diameter (cm) ± SD of black oak studied in 1995. Significant ($p < 0.05$) differences are indicated within a column by different letters. Separations were made using FPLSD. Significant differences for ecotype main effect, across the bottom row for North and South Shores, are indicated similarly.

Crown Dieback Severity	Residential Areas	Urban Parks	Forested Areas	Crown Category Mean
	North Shore			
Low	50.8 ± 12.6 a	53.4 ± 10.6 a	36.1 ± 26.2 a	47.1 ± 18.5 a
Moderate	53.34 ± 19.4 a	50.3 ± 10.3 a	24.8 ± 10.6 a	42.6 ± 18.2 a
Severe	44.7 ± 13.4 a	46.4 ± 14.4 a	30.6 ± 7.3 a	40.4 ± 18.0 a
	Ecotype Means (crown dieback severity pooled)			
	49.5 ± 14.9 a	50 ± 11.5 a	30.5 ± 17.0 b	
	South Shore			
Low	60.1 ± 16.6 a	46.9 ± 21.6 a	21.7 ± 13.8 a	43 ± 23.5 a
Moderate	54.8 ± 15.2 ab	38.0 ± 13.1 ab	26.9 ± 14.0 a	40.4 ± 18.0 ab
Severe	45.21 ± 10.8 b	30.9 ± 9.1 b	23.0 ± 8.9 a	32.7 ± 13.1 b
	Ecotype Means (crown dieback severity pooled)			
	53.7 ± 15.3 a	39.2 ± 16.8 b	23.8 ± 12.3 c	

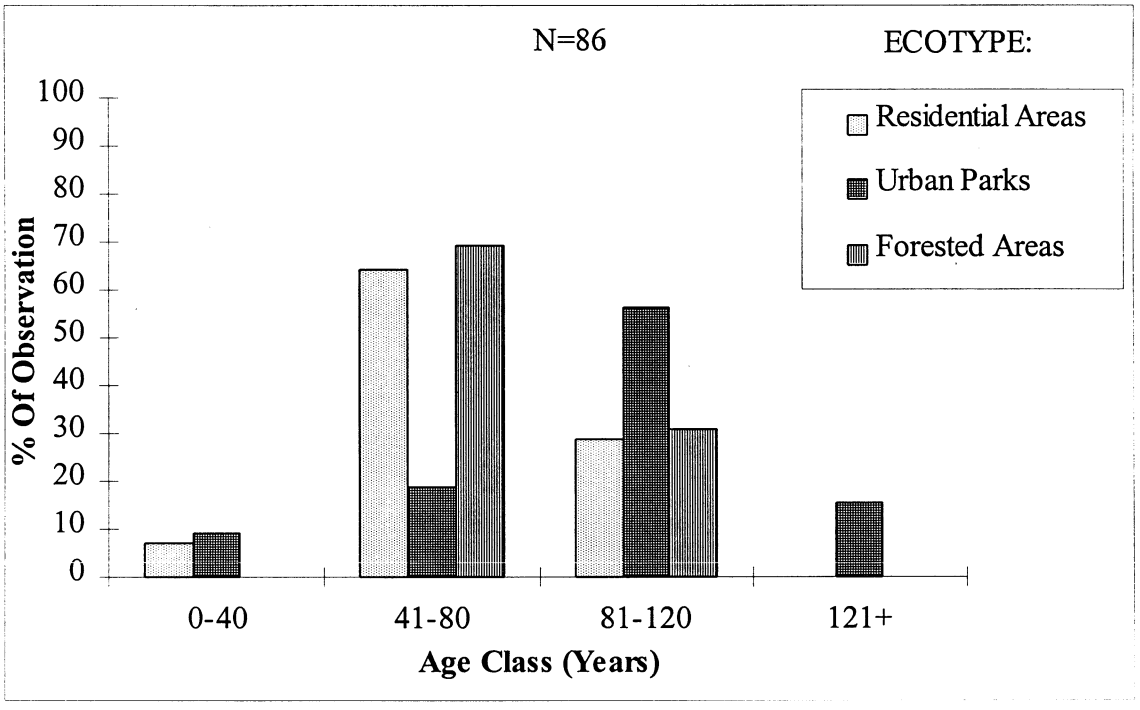


FIGURE 5. Ages of black oaks surveyed in 1995 on the North Shore.

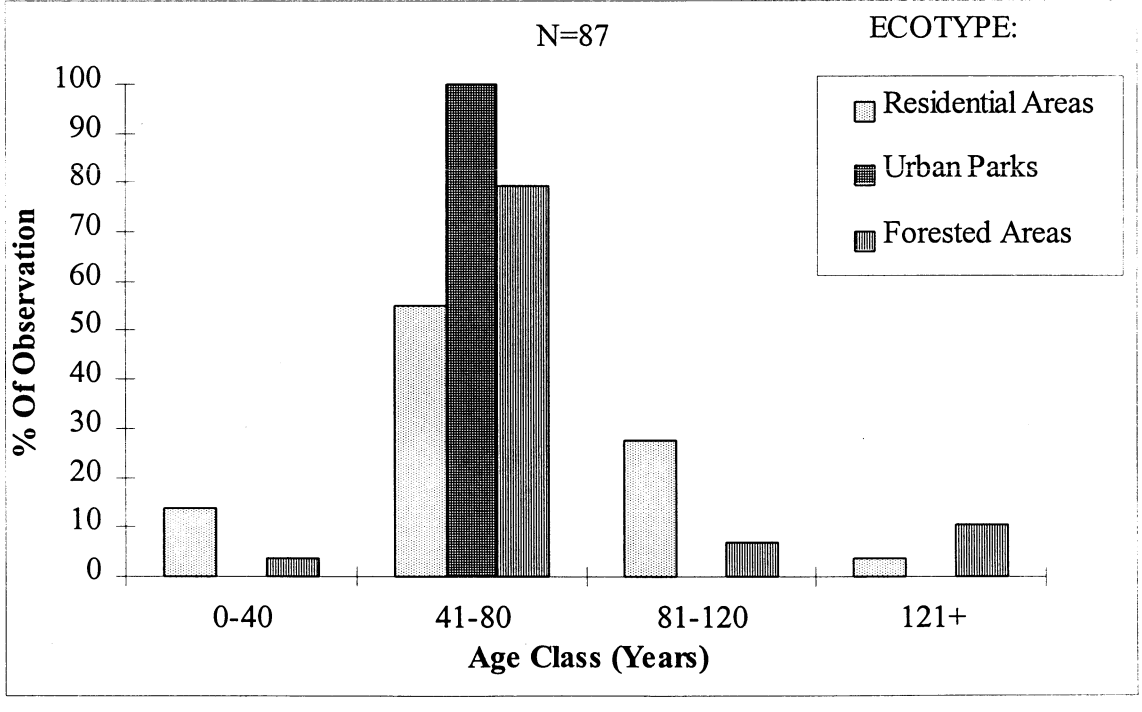


FIGURE 6. Ages of black oaks surveyed in 1995 on the South Shore.

both sites, the number of twig galls declined sharply in 1994 and remained low in 1995. In urban parks a similar trend was found, but was evident on both the North and South Shores. In the urban park ecotype on the North Shore, the number of twig galls was significantly greater on trees with severe dieback for only 2 (1991 and 1992) of the 6 years (t-test $p<0.05$) (Figure 8). On the South Shore, the number of twig galls differed significantly for 3 (1990, 1992, 1993) of 6 years.

Insect numbers showed considerably less year-to-year variability in forested areas than in residential areas or urban parks. On the North Shore, the number of twig gall declined gradually from 1990-1995 and was statistically similar (t-test $p>0.05$) among crown categories for all years at both sites (Figure 9). Few twig galls were found in 1994 and 1995, but populations did not drop abruptly in any year, as observed in residential areas and urban parks.

Twig Lengths. Twig length growth was significantly greater for trees in residential areas and urban parks than in forested areas for the North Shore (Table 10). Twig lengths on trees with severe dieback were significantly shorter than those on trees showing few symptoms of dieback in urban parks and forested areas. This pattern was not consistent on the South Shore, as no significant differences were detected among ecotypes (Table 10). Significant differences among crown categories were detected only in urban parks, where twig lengths were significantly greater on trees with low crown dieback than on trees with severe symptoms.

Increment Core Analysis. Basal area growth fluctuations, as reflected in increment cores, varied among ecotypes and between the North and South Shore sites. Mean 25-year

TABLE 9. Mean no. twig galls per surveyed branch + SD of black oak studied in 1995. Significant ($p < 0.05$) differences are indicated within a column by different letters. Separations were made using FPLSD. Significant differences for ecotype main effect, across the bottom row for North and South Shores, are indicated similarly.

Crown Dieback Severity	Residential Areas	Urban Parks	Forested Areas	Crown Category Mean
	North Shore			
Low	1.9 ± 4.6 b	1.8 ± 3.1 c	4.1 ± 7.1 a	2.4 ± 4.9 b
Moderate	7.9 ± 13.3 a	6.1 ± 14.3 b	4.1 ± 7.4 a	5.9 ± 12.2 ab
Severe	8.1 ± 10.8 a	10.3 ± 18.4 a	5.3 ± 9.3 a	8.3 ± 13.9 a
	Ecotype Means (crown dieback severity pooled)			
	5.6 ± 10.0 a	5.8 ± 13.6 a	4.4 ± 7.8 a	
	South Shore			
Low	6.4 ± 14.4 a	3.3 ± 5.1 b	3.0 ± 6.2 a	4.1 ± 9.4 b
Moderate	9.9 ± 14.5 a	6.1 ± 12.5 b	4.3 ± 9.9 a	7.1 ± 12.9 b
Severe	8.5 ± 13.0 a	15.5 ± 19.9 a	6.2 ± 10.4 a	9.3 ± 1.2 a
	Ecotype Means (crown dieback severity pooled)			
	8.4 ± 14.0 a	7.8 ± 14.2 a	4.6 ± 9.0 b	

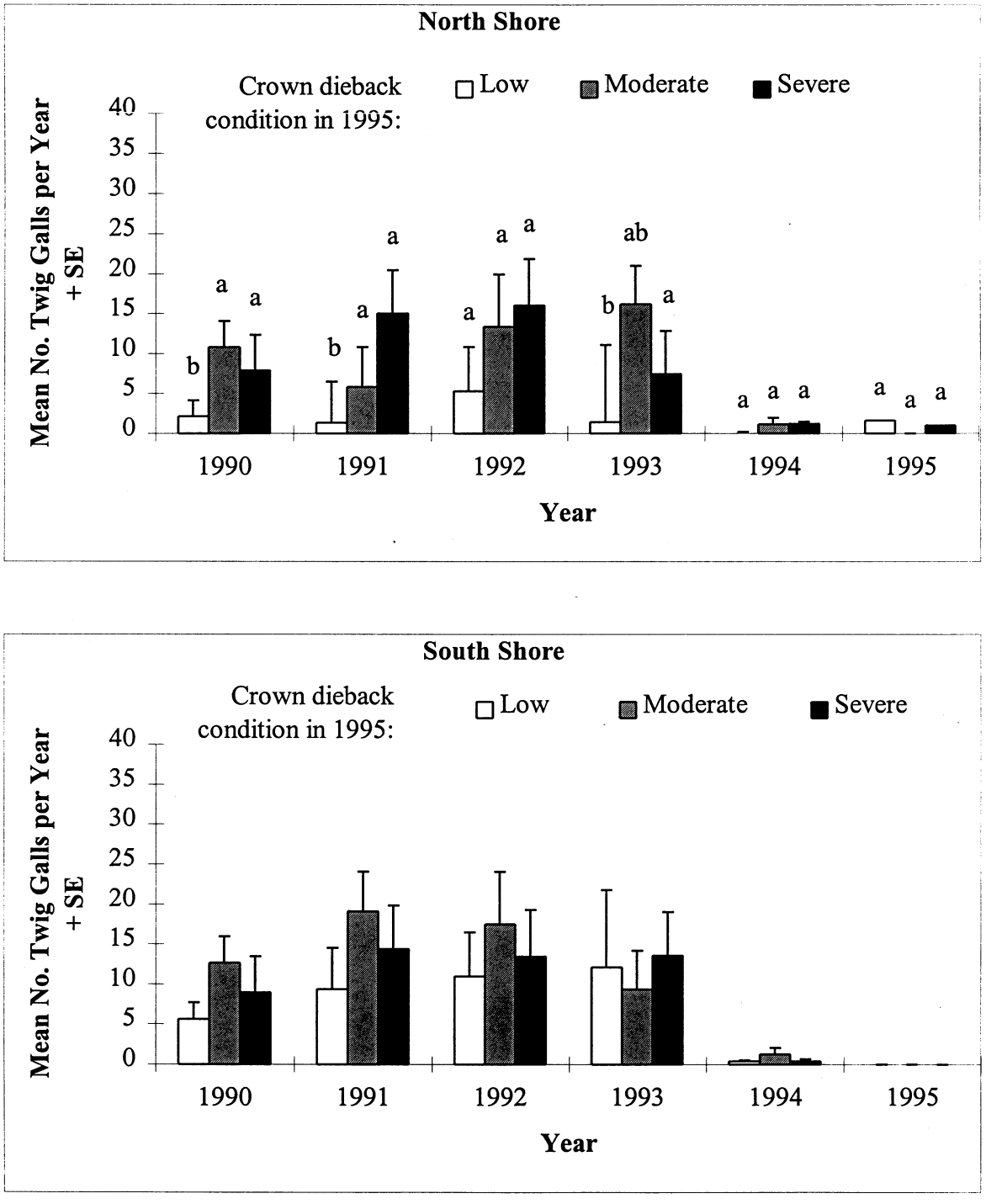


FIGURE 7. Mean number of gall wasps per year for residential areas on the North and South Shore sites. Significant differences within a year are indicated by different letters (separated by LSD). No differences were found at the South Shore.

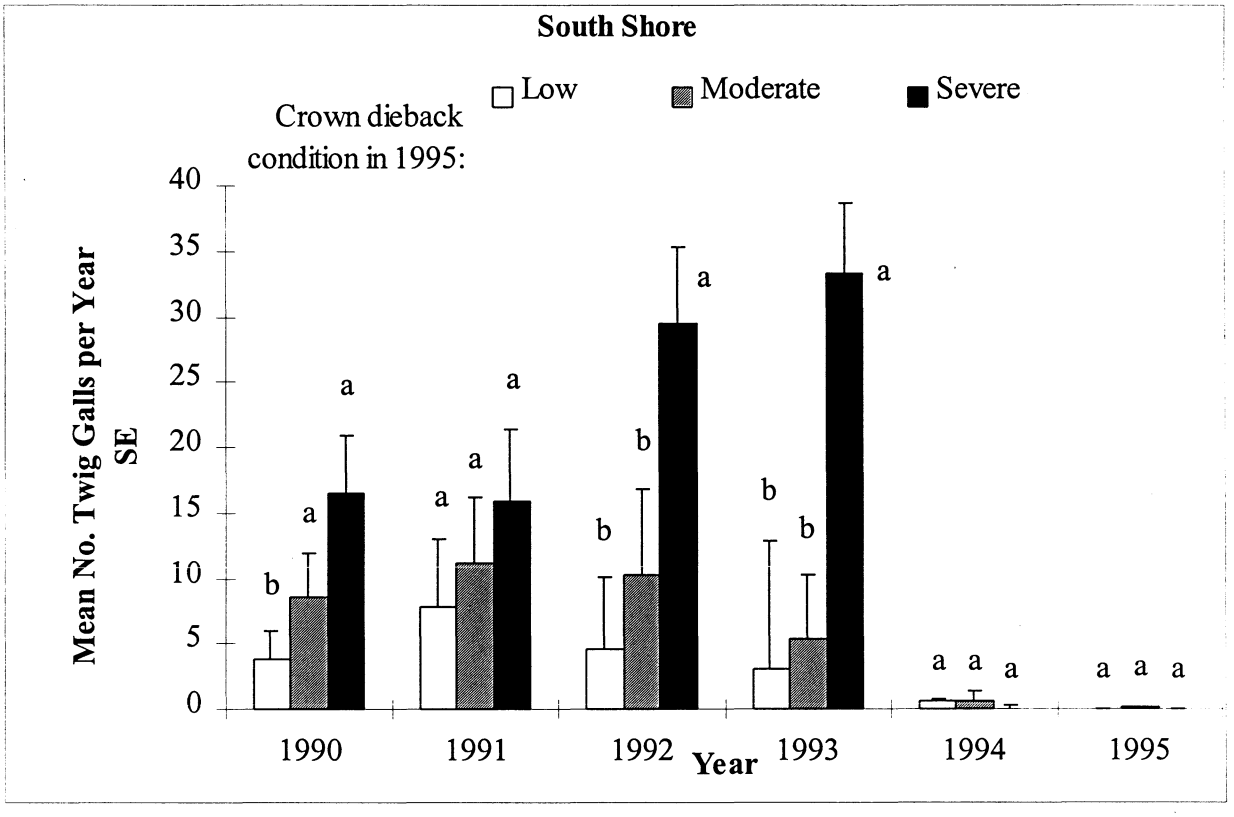
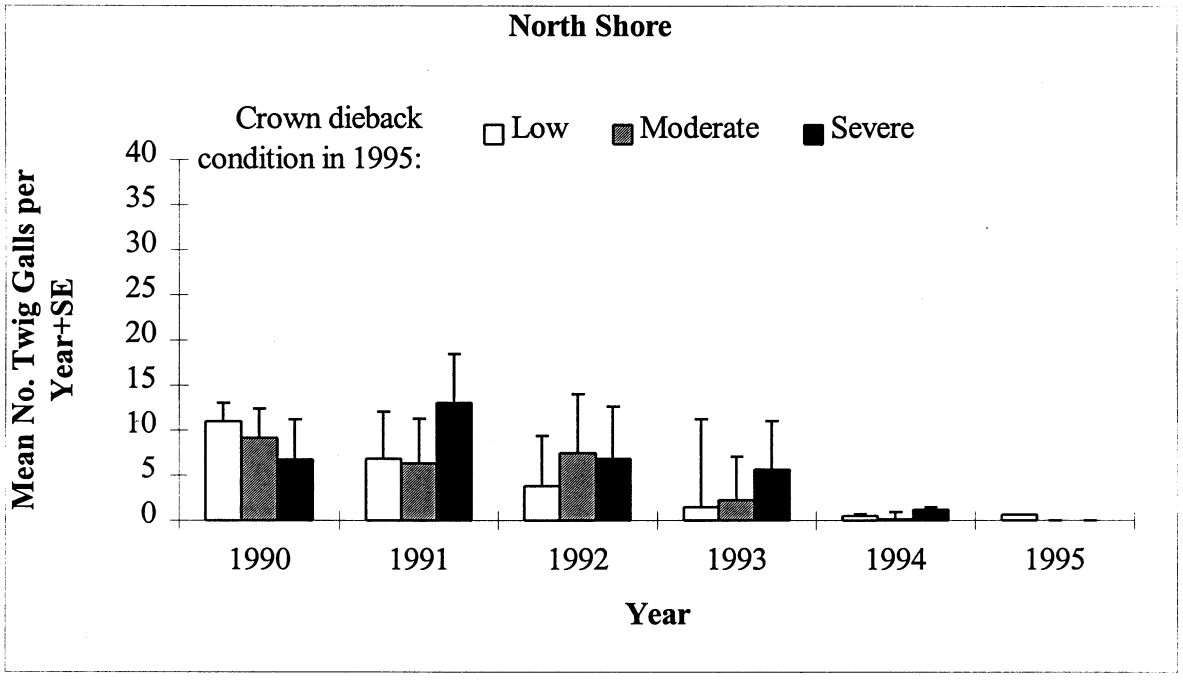


FIGURE 8. Mean number of gall wasps per year for urban parks on the North and South Shore sites. Significant ($p < 0.05$) differences within a year are indicated by different letters (separated by LSD).



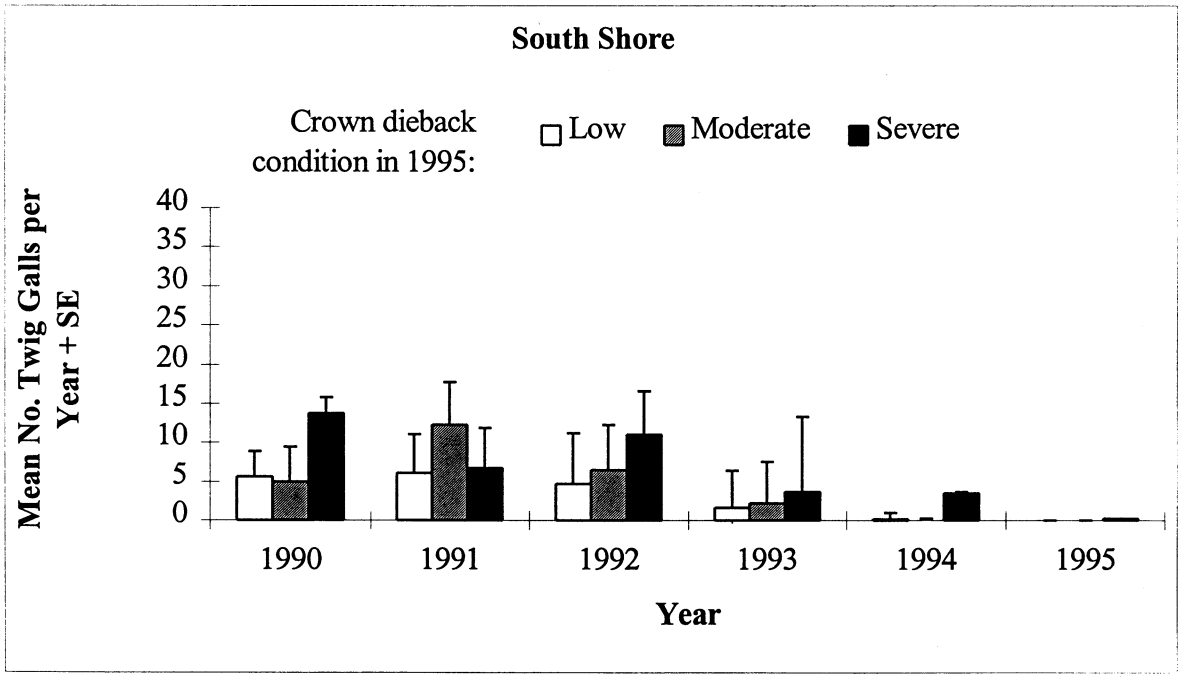


FIGURE 9. Mean number of gall wasps per year for forested areas on the North and South Shore sites. No significant dfferences within any year were found.

TABLE 10. Mean annual twig length (cm) ± SD of black oak studied in 1995. Significant ($p < 0.05$) differences are indicated within a column by different letters. Separations were made using FPLSD. Significant differences for ecotype main effect, across the bottom row for North and South Shores, are indicated similarly.

Crown Condition	Residential Areas		Urban Parks		Forested Areas		Crown Category Mean	
				[a] North Shore				
Low	10.9 ± 7.4	a	10.8 ± 5.7	a	10.7 ± 10.4	a	10.8 ± 7.6	a
Moderate	11.4 ± 6.9	a	11.2 ± 8.5	a	6.8 ± 4.9	b	9.8 ± 7.3	ab
Severe	9.7 ± 6.5	a	8.8 ± 5.9	b	7.9 ± 7.5	ab	8.8 ± 6.5	b
	Ecotype Means (crown dieback severity pooled)							
	10.6 ± 6.9	a	10.4 ± 6.9	a	8.3 ± 7.4	b		
				South Shore				
Low	10.0 ± 5.4	a	12.3 ± 5.9	a	8.9 ± 5.4	a	10.8 ± 7.6	a
Moderate	12.2 ± 8.7	a	9.7 ± 6.5	b	11.0 ± 7.3	a	9.7 ± 7.3	a
Severe	9.6 ± 7.3	a	9.5 ± 7.4	b	9.4 ± 6.5	a	8.9 ± 6.5	a
	Ecotype Means (crown dieback severity pooled)							
	10.7 ± 7.4	a	10.5 ± 6.7	a	9.6 ± 6.3	a		

[a] North shore comparisons were performed on log-transformed data.

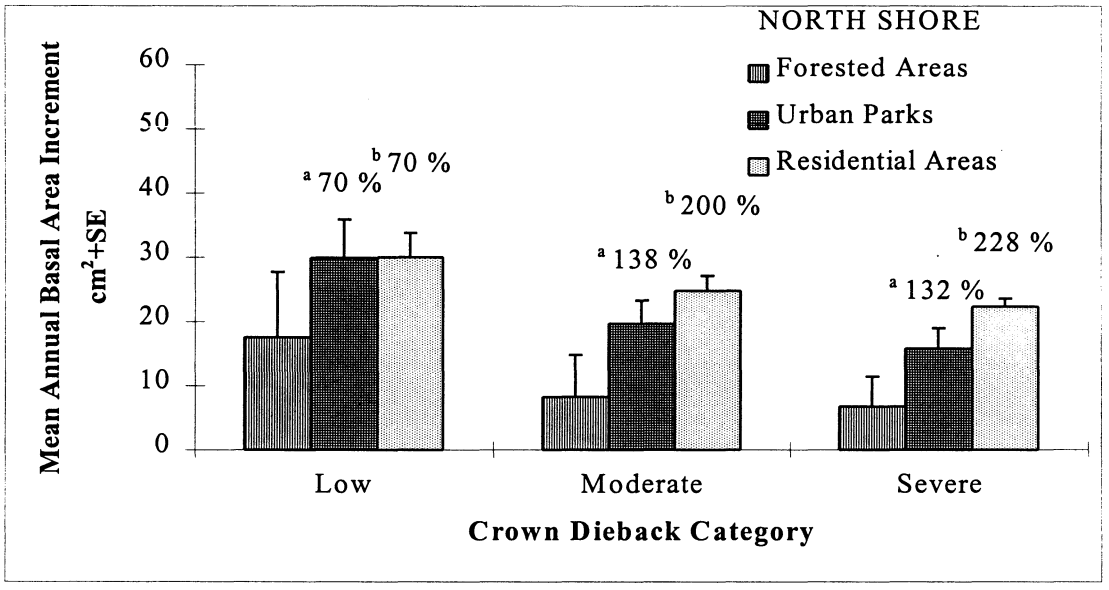
radial growth was greater in residential areas and urban parks than in forested areas, by as much as 600 % (Figure 10). In North Shore residential areas, mean periodic radial growth was significantly different between low and severe crown dieback classes during two periods, 1980-1984 and 1990-1994 (Figure 11). These periods correspond to two major events, a gypsy moth outbreak (1980-1981) and the gall wasp outbreak (1990-1994). Means between moderate and severe crown dieback classes were similar during these two periods as well. For all other periods, means were similar among low and severe crown dieback classes.

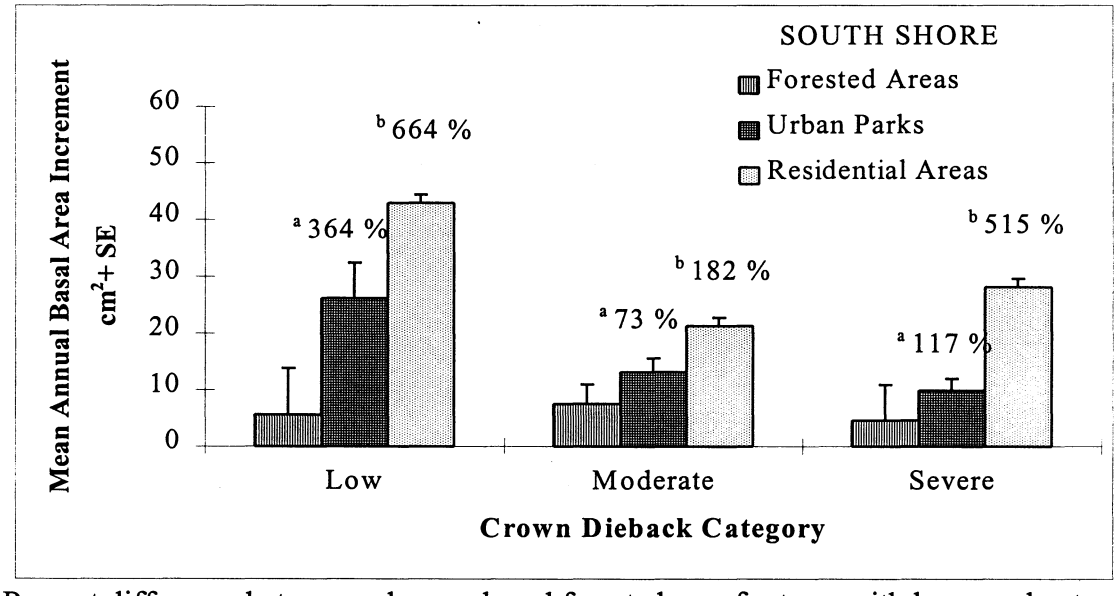
In South Shore residential areas, mean periodic radial growth was significantly different between low and severe crown dieback classes for all but the earliest period, 1970-1974 (Figure 12). Means between the moderate and severe crown dieback classes were similar for the last four/five periods.

In urban parks (North and South Shores), and forested areas (North Shore), mean periodic radial growth was significantly different between low and severe crown dieback classes for all 5 periods (Figures 13-15). Means between moderate and severe crown dieback classes were generally similar at all three sites. In South Shore forested areas, an entirely different trend was observed. At this site, means for trees with low crown dieback were significantly less than means for trees with severe and moderate crown dieback for 3/5 periods (Figure 16). During the two most recent periods, 1985-1989 and 1990-1994, means between low and severe crown dieback classes were similar.

On the North Shore, the effects of gypsy moth in 1980 were evident in the annual radial growth fluctuations of white oak trees (Figure 17). On the South Shore these effects were evident for two years, 1980 and 1981 (Figure 18). During the period in which gall wasps were active (1990-1994), mean radial growth increased steadily for white oak trees.

A similar growth pattern was observed among black oak with low crown dieback for the period 1990-1994 (A-Figures 5-9). Means for black oak with severe crown dieback generally decreased during the same period.





[a] Percent difference between urban park and forested area for trees with low, moderate, and severe crown dieback.

[b] Percent difference between residential and forested area for trees with low, moderate, and severe crown dieback

FIGURE 10. Mean 25-year radial growth for black oak in forested areas, urban parks and residential areas.

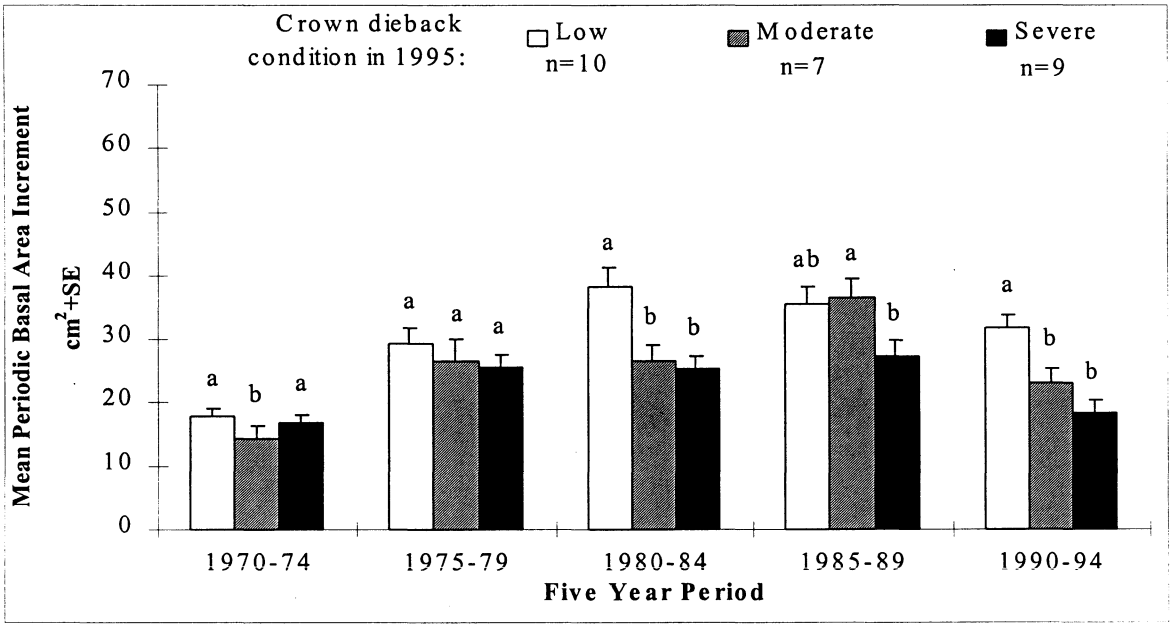


FIGURE 11. Mean periodic radial growth for trees in a North Shore residential area. Significant ($p < 0.05$) differences within a period are indicated by different letters (separated by LSD).

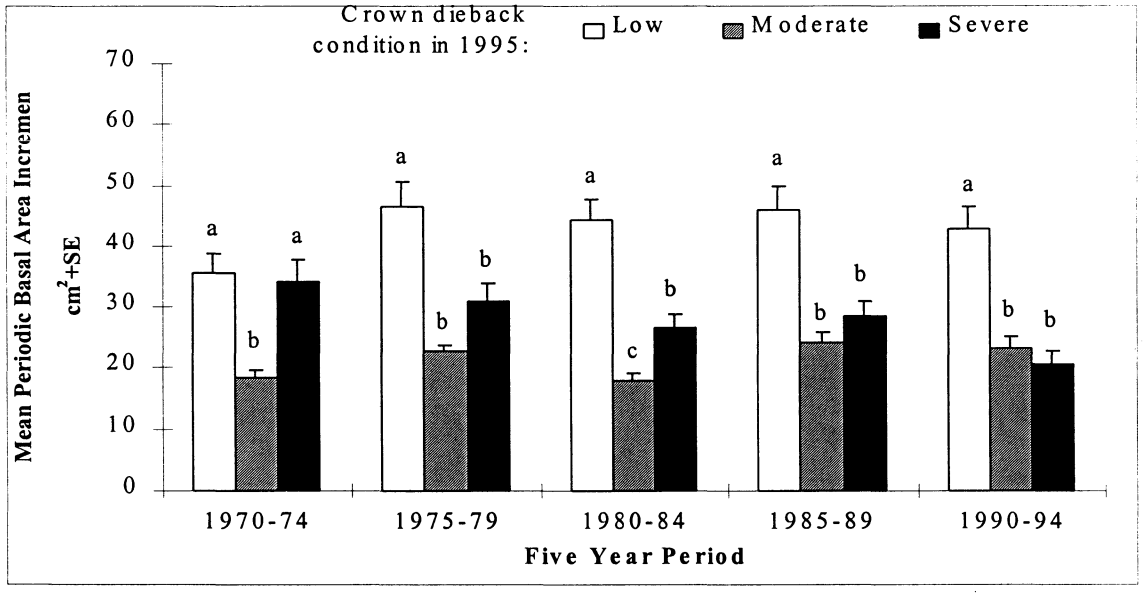


FIGURE 12. Mean periodic radial growth for trees in a South Shore residential area. Significant ($p < 0.05$) differences within a period are indicated by different letters (separated by LSD).

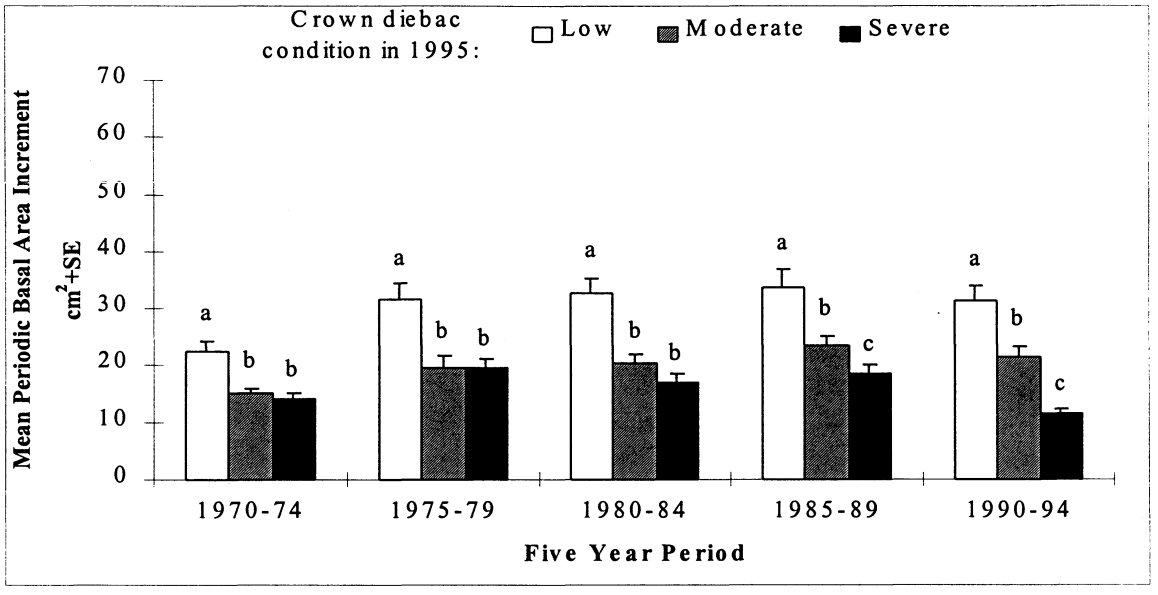


FIGURE 13. Mean periodic radial growth for trees in North Shore urban park. Significant ($p < 0.05$) differences within a period are indicated by different letters (separated by LSD).

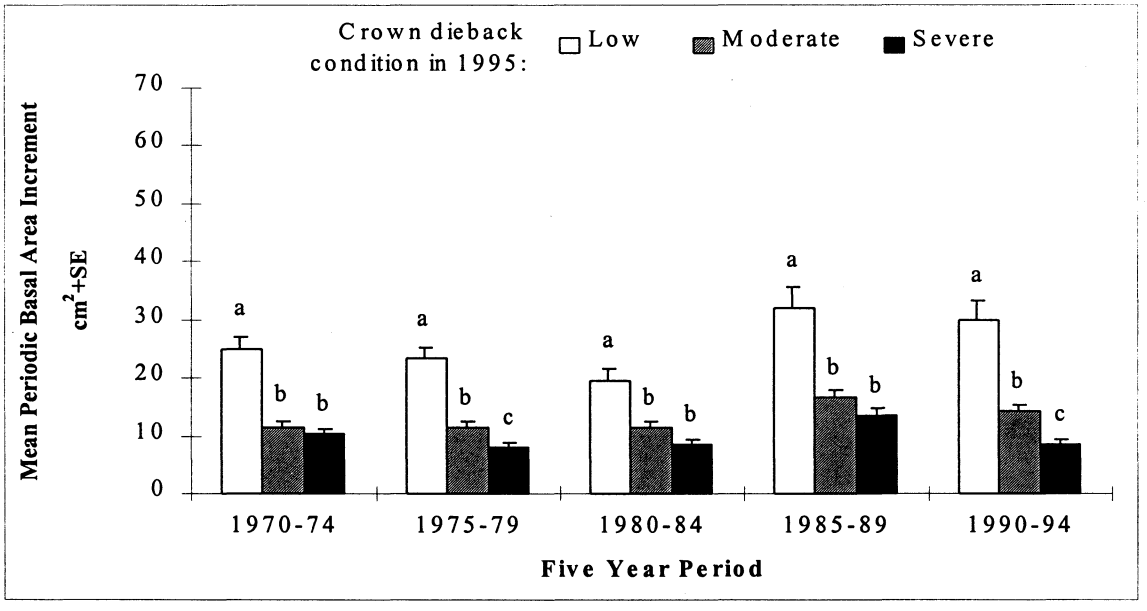


FIGURE 14. Mean periodic growth for trees in an urban park on the South Shore. Significant ($p< 0.05$) differences within a period are indicated by different letters (separated by LSD).

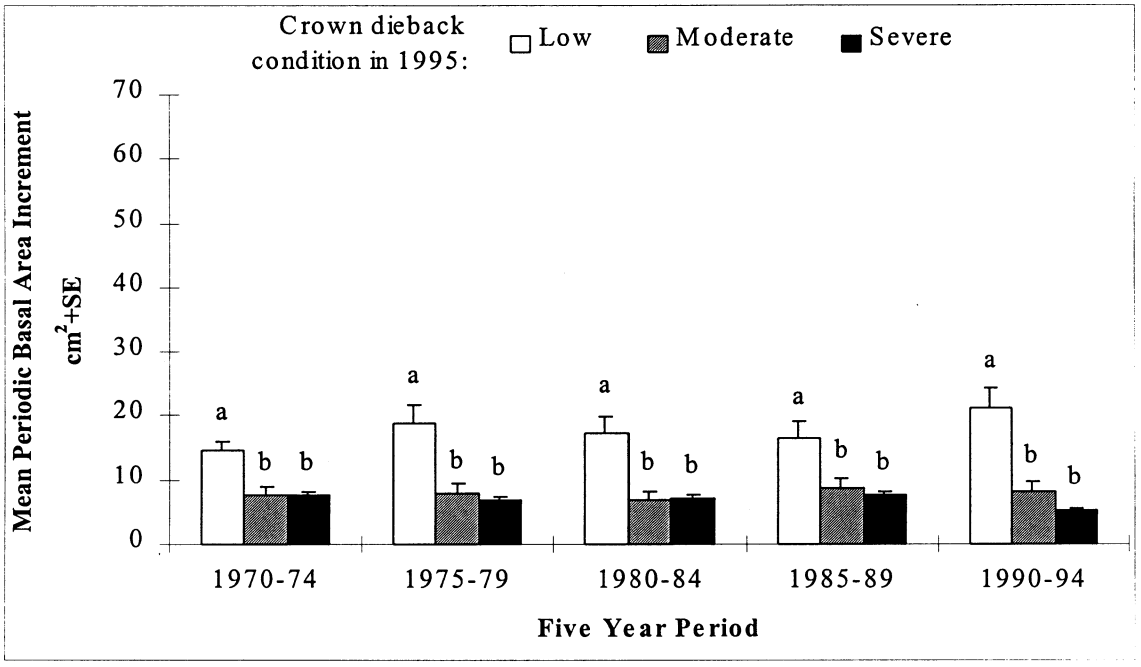


FIGURE 15. Mean periodic growth for trees in a forested area on the North Shore. Significant ($p < 0.05$) differences within a period are indicated by different letters (separated by LSD).

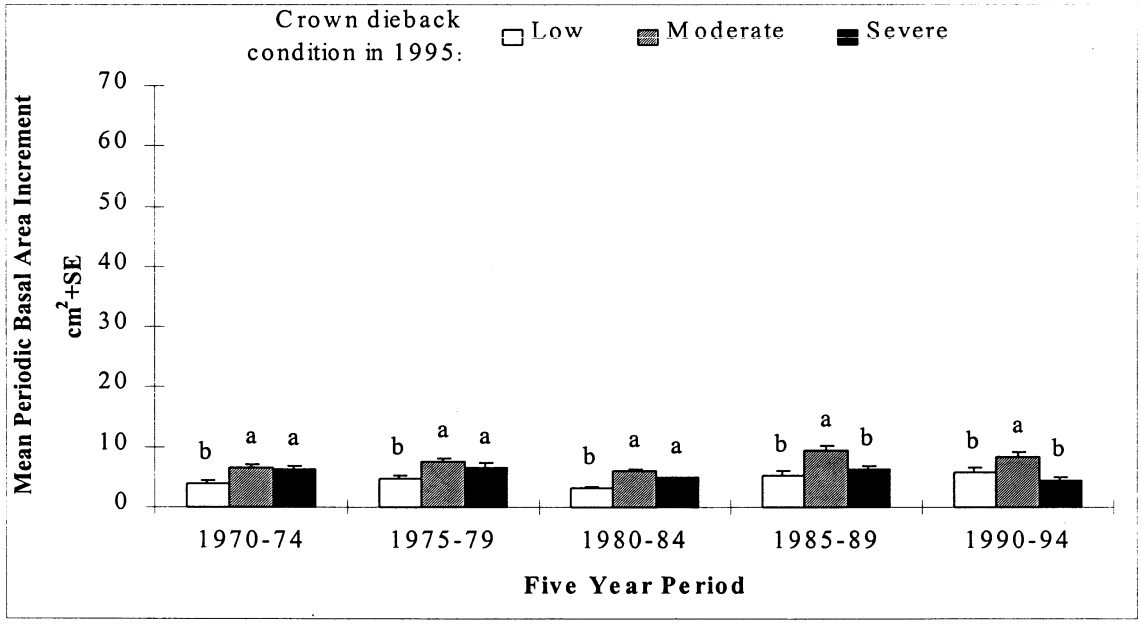


FIGURE 16. Mean periodic growth for trees in a forested area on the South Shore. Significant ($p < 0.05$) differences within a period are indicated by different letters (separated by LSD).

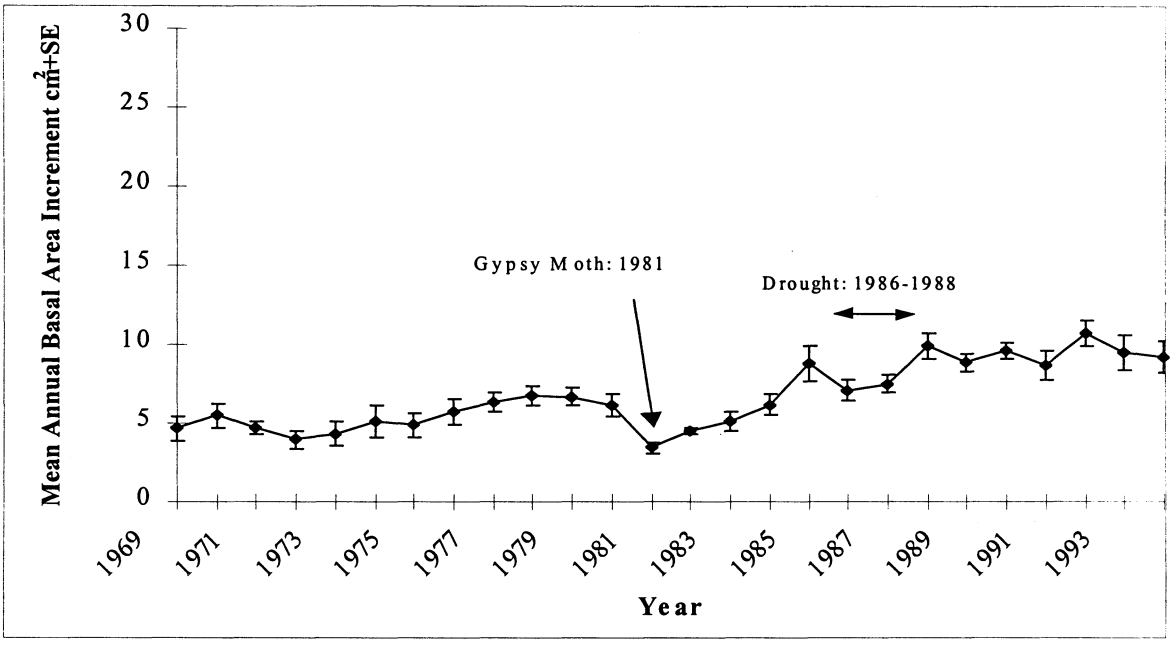


FIGURE 17. Mean annual radial growth of white oak trees from a forested area on the North Shore. N=10.

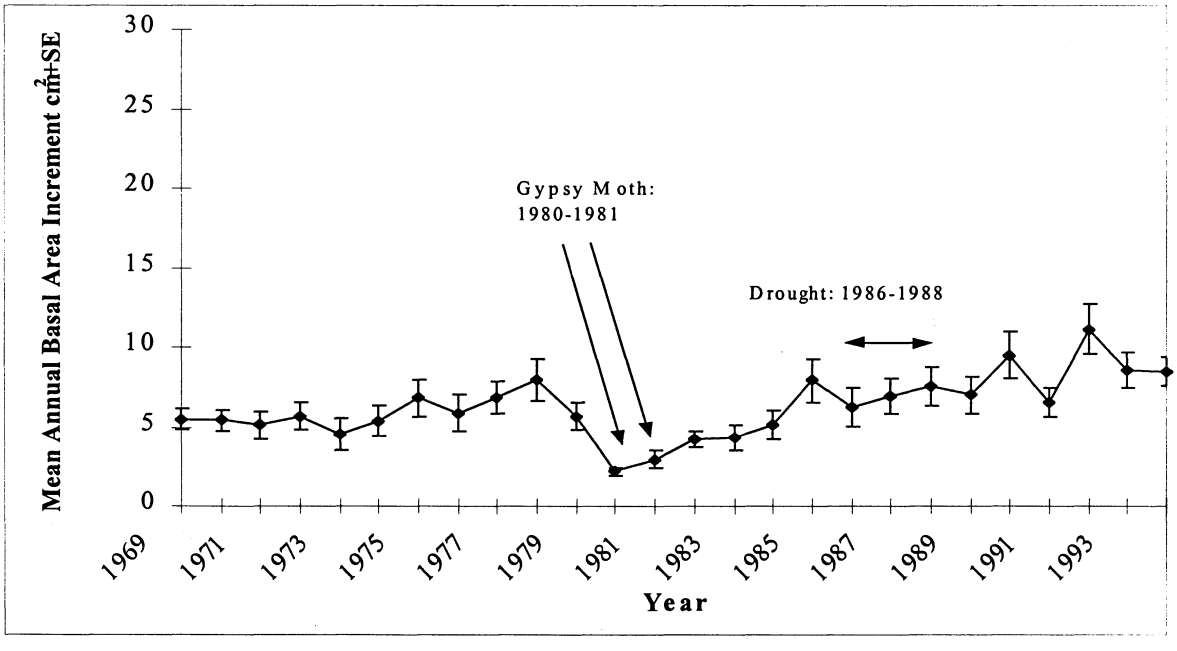


Figure 18. Mean annual radial growth for white oak trees from a forested area on the South Shore. N=10.

DISCUSSION

Extent and Severity of Decline. Symptoms of the decline were observed in all ecotypes studied -- residential areas, urban parks and forested areas. These symptoms, consistent with early anecdotal observations, include crown dieback, twig galling, and twig cankering. Trees in residential areas and urban parks were more severely impacted than those in forested areas. In residential areas, trees on the South Shore were the most impacted.

Percent crown dieback was similar among ecotypes (Table 3). Eighty % of trees in all ecotypes had less than 20 % crown dieback (Figure 3). It is likely that dieback in urban areas was greater in previous years than observed in the 1994 survey. Many homeowners undertook excessive pruning, watering, and premature removal of heavily infected trees which, during the current study, could not be accounted for. Further, trees with severe galling may have recovered prior to the survey due to water and fertilization treatments although there is no direct evidence of these treatments reversing the decline process. In unmanaged forests where insect numbers were lower, crown dieback was not altered artificially, therefore estimates are probably more accurate.

Twig galling was highly variable among ecotypes. Galls were most prevalent in urban parks and residential areas and lower in forested areas (Table 3). Eighty to 100 % twig galling was observed on 60 % of park trees and 40 % of residential area trees (Figure 3), while in forested areas, the largest percentage (40 % of trees) had between 0-20 % twig galling. These findings were generally consistent with insects found through twig dissections, in which insect numbers were generally higher in urban parks and residential areas than those in forested areas (Table 9). This corroborates with other studies of gall

wasps in which low levels of infestation are common in forested areas, while trees in urban areas were more prone to a greater intensity of infestation (Frankie et al. 1992, Bailey and Stange 1966). Correlations between % twig galling and % crown dieback suggest that the dieback in forested areas was due to causes other than the gall wasp. In urban areas, % crown dieback was positively correlated with twig galling. It is generally accepted that outbreaks of gall wasps are more often associated with urban areas because the overall health and isolation of urban trees is favorable to the proliferation of gall wasps. Healthy-vigorous trees are considered better host material for gall wasps and likely to support higher populations, as this type of insect is very much a plant parasite (Felt 1965, Mani 1964). In well-managed urban areas trees tend to be vigorous due to landscape care, although where management differs widely among residential areas and urban parks, variability in galling percentages is also likely.

The nature of galls produced by *B. ceropteroides* may also contribute to variability in the data. Galls occur within twigs and become visible only after the tree has overgrown the gall for two or three years, resulting in a visible gall. For this reason, twig galls are often inconspicuous and difficult to observe and in visual surveys, such as the 1994 survey in this study, more recent galls can be readily missed. Despite this, data from the 1995 branch dissections support the 1994 findings.

Twig cankering differed significantly, but was also highly variable among all ecotypes. Twig cankering was greater on trees in urban parks than those in residential and forested areas (Table 3). *Botryosphaeria* spp. are opportunists, and outbreaks on oak often correlate with predisposing factors such as drought, defoliation, or high levels of activity by cynipids. The fact that trees in urban parks were significantly more cankered suggests that

these trees were either predisposed to a greater extent than trees in residential or forested areas, either by the gall wasps or factors preceding them, or that the decline syndrome existed for a longer period of time in these areas. In addition, the relationship, if any, between galling and cankering is also not clear. Correlations between % galling and % cankering were inconsistent and weak for both urban and forested ecotypes. It is more likely that the incidence of cankers coincided with other stress factors preceding the gall wasps.

Tree height and diameter varied among ecotypes, but were significantly greater in urban parks and residential areas than in forested areas (Table 3). In most urban parks and residential areas, tree spacing is greater, and competition for light is less intense than in forested areas. Tree height and diameter reflect these different conditions, but site quality and tree age may also influence tree size. It is possible that trees in residential areas and urban parks were older than those found in forested areas, however, the study could not incorporate different size classes of trees because few small or suppressed trees were available for comparison. Severe crown dieback was observed on trees of a wide range of size and age groups and no significant correlations were found between tree size and crown dieback severity. Tree age and size do not appear to be important factors by which regional differences in decline among groups of trees in or between ecotypes can be understood.

Comparisons among soil associations. The purpose of comparing soil associations was to identify regions where decline symptoms were most severe, and to correlate these areas with features of the site or soil. Soil association is a useful taxonomic tool because it incorporates a variety of site characteristics, including relief, drainage, soil texture and structure (Brady and Weil 1996). The data suggest that a combination of site or soil factors predisposed trees on the South Shore differently from those in other areas on Long Island.

However, decline symptoms did not follow soil association patterns consistently across ecotypes. In residential areas the highest % crown dieback was observed on the South Shore (S.A. 4). In forested areas crown dieback was greatest in central areas (S.A.7); and in urban parks, central areas (S.A. 7) had the highest dieback (Tables 4-6). Soils on the North Shore have the highest sand component, rendering them more prone to drought, yet crown dieback on these soils was moderate in residential and forested areas. Crown dieback was greatest on S. A. 7, but not significantly so. These soils contain a fragipan layer that might limit tree growth but this is not reflected in crown dieback patterns. In residential areas on S. A. 5, crown dieback was high. This association occurs on barrier islands which provide poor habitat for black oaks, as confirmed by small diameter and heights of trees surveyed there. These areas exhibit poor soil structure and are prone to salt water flooding and salt-laden winds. No significant or consistent relationships among % crown dieback, % twig galling, % twig cankering and soil association were found.

Twig galling was similar among all but two soil associations for residential areas (Table 4) and among all soil associations in forested areas (Table 6). For residential areas, twig galling mirrored trends for crown dieback, and was generally high on the South Shore (S.A. 4), intermediate on the North Shore (S.A. 1 and 2), and low on the central and East End of Long Island (S.A. 3 and 8). Differences were significant only between the South Shore and East End. In forested areas the trends were opposite. Greater amounts of twig galling were observed on the North Shore (S.A. 1 and 2) than on the South Shore. There is no explanation for these inconsistent trends. Regional differences in terms of soil association do not consistently account for the occurrence of twig galling. Soil association was not an important predisposing factor affecting the severity of gall wasp infestation.

Twig cankering was similar among most soil associations in all three ecotypes. In residential areas cankering was significantly greater along the South Shore (S.A. 4) than on the east end (S.A. 9) (Table 4). These findings mirrored the intensity of twig galling at this ecotype. In forested areas, two soil associations were significantly different, S.A. 2 and 3. However, these associations lie adjacent to one another, and none of the parameters measured can explain these findings. In urban parks, cankering was similar among all soil associations. Twig cankering was not consistently explained by soil association alone.

Tree height and diameter differed significantly among soil associations for trees in residential and forested areas. In residential areas, trees with the largest height and diameter were found along the North Shore (S.A. 1) and on Shelter Island (S.A. 7). These soils occur on a glacial moraine, and are deep with variable topography. These findings are consistent with studies of black oak which found soil depth to be an important indicator of site index (Doolittle 1957). While all soil associations are classified as "deep" in the soil survey, local differences in topography and subsequent soil depth might explain why tree height was generally greater on glacial moraines than on other sites. Tree height and diameter were smallest on the soil association occurring on the barrier island (S.A. 5) (Table 4). This is consistent with the high levels of crown dieback observed and again reflects the depauperate conditions for black oak that occur in these areas.

Other factors have been implicated as causal agents for symptoms including storm damage or pollution. Storm damage, indicated by jagged branch wounds and missing tree tops, was present on fewer than 20 % of trees at all ecotypes. Basal injury occurred on less than 22 % of trees in any ecotype. Air pollution may have had an effect on the overall vigor of trees, but visual symptoms of pollution impacts on leaves, for example, were not found.

Trees that were closer to roads were not more heavily impacted than those further away. Herbicides are unlikely contributors, as trees with severe symptoms occurred on lawns with a wide range of weed management intensities. Salt stress due to snow removal is also unlikely because most trees were not adjacent to roads and therefore not likely to be exposed to excessive road salt. Stress from salt water is likely to have influenced trees growing along the barrier island soil association, S19. The small stature of the black oak surveyed there indicates that conditions were clearly unfavorable for growth. However, the large majority of trees surveyed were not located in areas at high risk area for salt water flooding or salt-laden wind.

The results from this survey indicate that the decline was widespread across Long Island. Trees with severe dieback were observed in residential areas, urban parks, and in forested areas, and across a variety of soil associations. It seems that publicity preceding this study may have overemphasized the extent and severity of the problem (Fullam 1994), since most trees had between 0-20 % crown dieback. Some park and private property owners did report substantial tree mortality, but the island as a whole was only moderately impacted. Some areas, particularly the South Shore, were heavily affected but symptoms were less severe in other regions. Symptoms were observed in all ecotypes and soil associations but overall, trees in urban parks and residential areas were more affected by the gall wasp and fungal canker than trees in forested areas.

Relationships among symptoms and site characteristics. The study in 1995 attempted to further define the relationships among symptoms (galling, cankering and crown dieback) and site characteristics (ecotype). This study examined, in detail, the decline syndrome from trees on two sites (North and South Shores) that occurred in residential,

urban park, and forested areas, and were selected to have a priori low, moderate or severe crown dieback (Table 2). These locations were chosen because crown dieback means were similar between their respective soil association in 1994 survey and twig galls were observed in moderate to high intensities. Sample sizes were uneven because many trees, particularly those in forested areas, did not contain branches that were accessible with a pole pruner. In some cases, trees were selected that had heart rot, and increment cores could not be obtained.

The height and diameter of trees with severe dieback were not consistently smaller at either site. On the North Shore, the diameter and height of trees in urban parks were significantly greater than those in residential or forested areas, as observed in the 1994 survey. On the South Shore, no significant differences in height or diameter among ecotypes were found. Counting of tree rings from increment cores did not show obvious differences among the ecotypes or among crown categories that might explain the high degree of dieback that occurred there. Trees representing a single size class were not visibly more affected at any ecotype or location (Figures 5 and 6). It is difficult to conclude from this study alone whether trees of all age groups were susceptible since the majority of trees were greater than 50 years of age, and no individuals were less than 25 years.

The mean number of galls excised from twigs differed significantly among ecotypes for the South Shore, and were less in forested areas than in urban parks and residential areas. The isolation of trees in urban parks and residential areas may have resulted in locally high populations of gall wasps. Some important predators of gall wasps, mainly chalcidoids and inquilines, overwinter in leaf litter and are deterred by sanitary conditions found in urban areas. Parasitoids are known regulators of gall wasps, and in their absence outbreak populations of gall wasps have been reported (Washburn and Cornell 1981, Bailey and

Stange 1966). Gall wasp populations in residential areas and urban parks may have temporarily escaped parasitism and therefore experienced outbreak proportions (Frankie et al. 1992). In forested areas, crown dieback was likely due to other factors besides the gall wasp.

Trees with the most severe crown dieback had significantly greater number of residual twig galls than trees showing few symptoms at both shores (Table 9). Previous studies of gall wasps have shown that cynipid wasps, in general, prefer more vigorous hosts (Caouette and Price 1989, Washburn and Cornell 1981, Price 1991). On Long Island, all trees surveyed were physiologically mature. Results from the increment core analysis showed that trees, especially in the urban areas, were more vigorous than those in forested areas. Among the trees surveyed, some had shown reduced incremental growth in the past 10-15 years. Trees with this characteristic reduction in growth were most susceptible to gall wasp attack. While overall vigor may be favorable to gall wasps trees that were predisposed from previous events were most symptomatic.

In urban parks at both sites, trees with severe dieback had significantly greater numbers of twig galls than trees with low dieback (Table 9). It seems questionable that gall wasps, knowing their tendencies for vigorous hosts, would target trees predisposed by other factors. However, it is not likely that individual trees were "targeted" by gall wasps. Instead, high insect populations probably resulted from a combination of chance and host re-infection. Factors governing cynipid host dispersal are not known, but it is likely that insects dispersed to the closest suitable host, and in urban areas where trees are far apart, subsequent generations relied on the same host for reinfection. The most effected trees may have encouraged large populations of *B. ceropteroides* forcing dispersal onto nearby trees.

The large numbers of remnant insects removed from the twigs of stressed trees may have resulted from higher mortality and lower successes of gall wasps on this host material. However, this is unlikely since exit holes are visible on twigs for 2-3 years after the adult's departure. On older twigs, reproductive success was nearly impossible to discern because of the thicker bark, which is why this study was confined to newer growth. The fact that insect numbers were similar among crown categories in forested areas at both shores further supports the theory that trees belonging to a single crown category were not targeted, rather insect numbers had become regionally high.

A greater number of significant differences among ecotype and crown category were observed on the North Shore than the South Shore. It is possible that the more uneven sample sizes of the North Shore contributed to a lack of significance there. Trees, particularly those in forested areas, were tall and straight, with few accessible lower branches, thus branch samples could not be obtained from most trees. In addition, living trees with severe crown dieback were difficult to find at this site. Many large trees at this site were dead, suggesting that the decline may have begun earlier than at the South Shore.

Annual fluctuations in numbers of twig galls suggest that populations of *B. ceropteroides* responded differently in various ecotypes. In urban park and residential areas, their numbers were high in 1992-1993 and declined sharply in 1994. In forested areas twig gall numbers declined gradually from 1990-1995. Two major distinctions between the urban areas, (parks and residential areas combined) and forested areas might explain these findings. In forested areas, trees are more densely stocked, permitting easier dispersal for the gall wasp which is not likely to travel long distances. In urban areas their populations were likely concentrated on fewer available hosts resulting in greater reinfection on the same host.

Furthermore, the increased number of potential habitats in forested areas may have hosted predators or parasitoids that were not able to thrive in urban environments. It is possible that gall wasp populations were more easily targeted by a variety of predators and parasitoids in forested areas, keeping their numbers low, however parasitoids alone cannot explain the seemingly simultaneous decline in their numbers in 1994 across all ecotypes. If major predators overwinter in leaf litter, it is unlikely that they could have contributed significantly to the population decline of *B. ceropteroides* in urban areas, particularly since leaf litter is usually removed. In addition, 99 % of the insects found in twigs were identified as *B. ceropteroides*. If parasitoids were present, we would expect to find evidence within twigs or twig galls of either remnant parasitoids, or exit holes in the bark. The population crash of *B. ceropteroides* that occurred, based on observations from branch samples, is likely to have occurred from a combination of parasitoid activity and other regional factors such as weather.

The data do not suggest a strong pattern with which to explain the syndrome, its extent and severity, or various contributing factors. This may be due to the nature of gall wasps. Gall wasps are cited as problematic urban pests in a number of areas across the United States (Frankie et al 1992, Bailey and Stange 1966). The actual factors that influence gall wasp host selection and population intensity are not known for most cynipids. Ecological pressures affecting the population cycle of gall wasps (Gilbert et al. 1994), or subtle differences in tree chemistry, may have influenced the geographic and ecological patterns of decline that were observed on Long Island. There is no obvious explanation for both the sudden outbreak and crash of gall wasps on Long Island. Twig galls indicating the presence of a gall wasp were observed in Queens and in southern Connecticut but none of these trees exhibited severe dieback in association with the twig galls. It is possible that the

gall wasp responded to regional climatic changes or conditions unique to central/eastern Long Island, perhaps related to weather, that affected trees in all ecotypes.

Relationships between radial growth and decline symptoms. Radial basal area growth, measured from increment core samples, provides a measure of tree vigor over many years. Peaks and troughs in growth rates created by weather events are useful aids in cross-dating, a method by which growth years are verified with the population of trees (Fritts 1976). A number of events appearing in the tree rings were common to all studied. On the North Shore, a decline in the radial growth was observed in 1981. On the South Shore, a decline was observed in 1980 and 1981. These growth patterns coincide well with reported gypsy moth outbreaks on the South Shore in 1980 (Williams 1980) and on the North Shore in 1981 (Barron 1981, Faust 1981). These defoliation events are also evident in the radial growth patterns of white oak trees. A decline in radial growth between the years 1985 and 1986 was observed in all trees studied as well (A-Figures 5-10). This coincides with a regional drought that occurred on Long Island during the 1986 growing season. Rainfall amounts were below average in 1980-1981 during the gypsy moth outbreak, but from 1982-1984 rainfall amounts exceeded the average (NRCC 1996) (A-Figure 4).

Periodic radial basal area growth was compared among trees of different crown categories within each ecotype to ascertain if growth was reduced prior to the arrival of the gall wasp, estimated to the mid-late 1980s. Differences in periodic radial growth were found among crown categories within each ecotype, and means were often significantly less for trees with severe dieback than those with low dieback prior to 1980. Similarly, mean annual twig lengths were significantly greater for trees with low dieback than for those with severe symptoms on the North Shore. Mean annual twig lengths on the South Shore were similar

among both ecotype and location. In addition, means in urban parks and residential areas were significantly greater than those in forested areas at the same site.

The gypsy moth activity of the early 1980s and the gall wasps were not as effective at reducing growth of trees with higher vigor (fuller crowns) as compared to trees with lower vigor. Evidence of reduced growth was particularly obvious at the residential area on the North Shore. At this site, radial growth of trees with severe dieback was significantly less than trees that with low dieback in 1995 for two periods: 1980-1984, the period following the gypsy moth outbreak, and 1990-1994, the period during which gall wasps were active. The radial growth immediately following the 1981 gypsy moth event sharply increased for trees with low dieback, and decreased among trees with severe dieback. It is possible that the gypsy moth suppressed the growth of trees that were later affected by the gall wasp. The decrease in the radial growth from 1990-1994 observed on trees with severe crown dieback likely resulted from high numbers of gall wasps and reduced vigor prior to attack. In urban parks, some event predating the gypsy moth outbreak suppressed the growth of trees on the North Shore. In residential areas on the South Shore, the radial growth of trees with low and severe dieback was similar from 1970-1974, but differed significantly for all other periods (Figure 12). In urban parks, trees with severe dieback were predisposed well before 1970, as indicated by the increment cores. The height of these trees was the largest of all three ecotypes. The high and subsequent nutrient demands render vigorous trees more sensitive to crown defects making them ideal candidates for decline.

In the forested areas, two different trends were apparent. On the North Shore, the mean periodic radial growth of trees with low dieback was significantly greater than trees with severe dieback for all five time periods. On the South Shore, a completely different

pattern was observed for which there is no obvious explanation. The radial growth of trees with severe dieback was significantly greater than trees with low dieback from 1970-1974, 1975-1979 and from 1980-1984. Radial growth was similar between these two groups for the remaining two time periods (1985-1989 and 1990-1994) (Figure 16). It is worth noting that at this site, no significant differences were observed among crown categories for any variable studied, including tree height, diameter, twig galls, and twig length. Some other variable that was not considered in this study is likely contributing to the dieback in this area.

White oak is not a known host for *B. ceropteroides*, and from 1990-1994 during peak gall wasp activity, the radial growth of this species generally increased (Figures 17 and 18). This pattern resembles the growth pattern for black oak exhibiting low crown dieback for the same period, suggesting that the impact of gall wasps on the radial growth of these trees was minimal. Insect numbers were not consistently low on these trees, instead, high variability was observed. Trees with low dieback exhibited a tolerance to low or moderate levels of insect attack in contrast to those with moderate and severe dieback that showed a distinct decrease in radial growth for the same period. Thus the impact of gall wasps on the radial growth was more severe on trees with reduced growth prior to onset of gall wasps attack. The combination of previous defoliation outbreaks with other factors, such as the drought in 1986, may have further reduced the vigor of trees that already had limited nutrient stores. It appears that trees with severe crown dieback were not necessarily more impacted by the gall wasp, but that these trees lacked the resources to recover from sustained attack.

Proposed Model of Oak Decline. Evidence from the current study supports the decline model proposed by Mueller-Dombois (1992) and Manion (1991), although the biology of this decline has only been superficially studied. Clearly the dieback observed was

the result of multiple agents, biotic and abiotic, unique to, but not limited to, residential areas and urban parks. Decline was associated with dominant and codominant trees only, and no single tree was less than 25 years old. The high mineral and nutrient requirements of these trees indicates that they are prime candidates to dieback and decline, in accordance with Manion's model. As an aging component of urban and natural forests, Mueller-Dombois' concept of "synchronous cohort senescence" also applies.

A variety of factors likely encouraged black oaks to decline on Long Island. Characteristics of the sites, soils, and the maturity of the trees are long term predisposing factors. Soils on Long Island are generally deep, but highly prone to drought. In urban areas, soil compaction may have impacted certain trees. The drought and defoliation events of the 1980s are likely inciting factors, reducing the vigor of already-stressed trees. *B. ceropteroides* and *Botryosphaeria* sp. arrived last, killing some trees and substantially reducing the growth of others. In urban parks and residential areas, gall wasp populations were favored by the conditions of host trees there. The mode by which *Botryosphaeria* entered twigs is not known. *Botryosphaeria* is an effective pulse perturbation factor (Mueller-Dombois 1992) further inciting decline on stressed trees rather than serving as a direct contributor. Since so little is known about the ecology of the cynipid gall wasp, its relationship, if any, with the fungus is not known. Factors influencing host selection by cynipids have not been elucidated for any species of cynipid. Further, as susceptible trees entered the "decline spiral" (Manion 1991), adjacent trees that were not currently under attack become involved due to higher populations of the wasp and canker, thereby increasing the extent and severity of the symptoms and making this syndrome appear to be a regional decline. In general, cynipids do not kill their hosts, but in association with previous stress

events, tree vigor may be reduced to the point where dieback and mortality occur through a decline syndrome. The decline has since abated, as indicated by observations made in 1996. However, it is likely that the cycle of decline will return, triggered by a series of inciting and contributing factors like those described in this thesis. Trees that survived attack by gall wasps in the 1990s may become more susceptible to decline in the future.

CONCLUSIONS

- There was a high degree of variation within plots and among ecotypes. Symptoms were not concentrated on a single soil association or region on Long Island, although trees on the South Shore of Long Island was consistently more symptomatic than other regions.
- Crown dieback, and signs of the gall wasp and fungal canker were more evident in residential areas and urban parks where cynipid gall wasp populations were concentrated on individual, isolated trees. Tree vigor in urban parks and residential areas was generally higher than in forested areas, which may have contributed to the high numbers of gall wasps. In addition, insects in urban areas may have escaped predators and parasitoids more effectively than trees in forested areas.
- Gall wasp numbers increased steadily from 1990-1993 in residential areas and urban parks and declined abruptly in 1994. In forested areas, their numbers declined gradually from 1990-1995. All trees, regardless of crown condition, sustained some level of galling. Trees with reduced growth prior to 1980 were generally more susceptible to dieback.
- Prior defoliation and drought events, tree maturity, genetic susceptibility, and other unidentified site factors likely contributed to the reduction in growth observed on trees with severe decline symptoms in 1995. By 1996 recovery was evident on most trees and insect populations had declined substantially.

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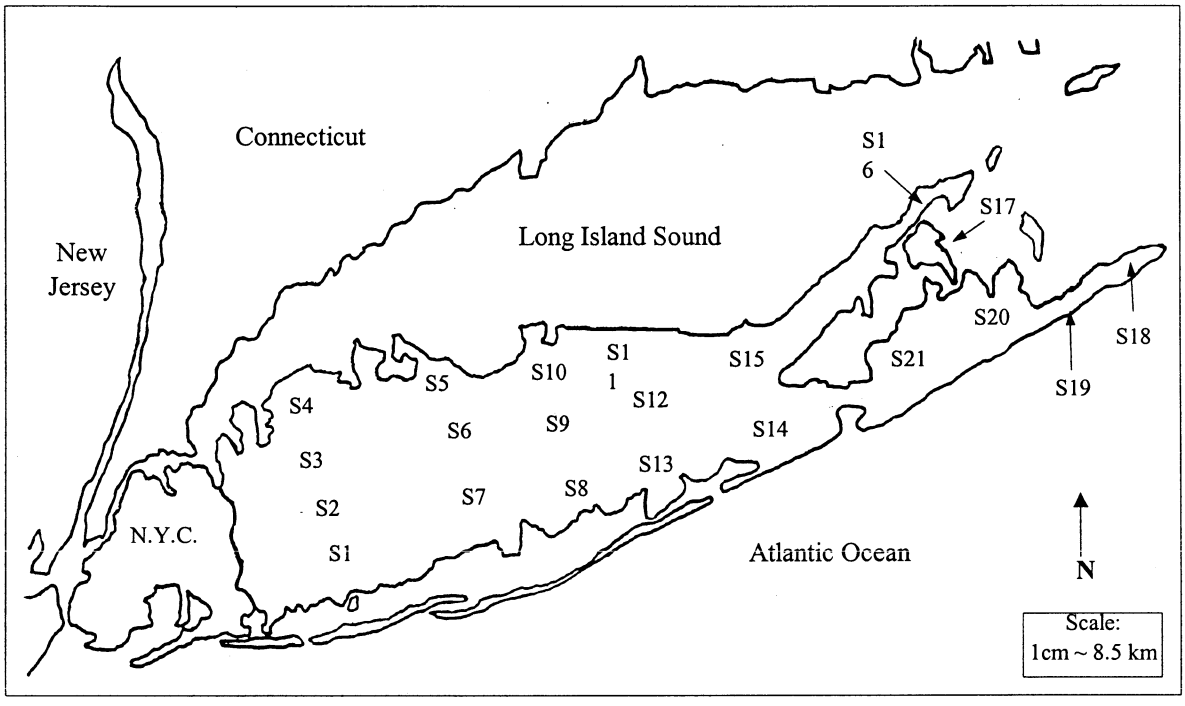
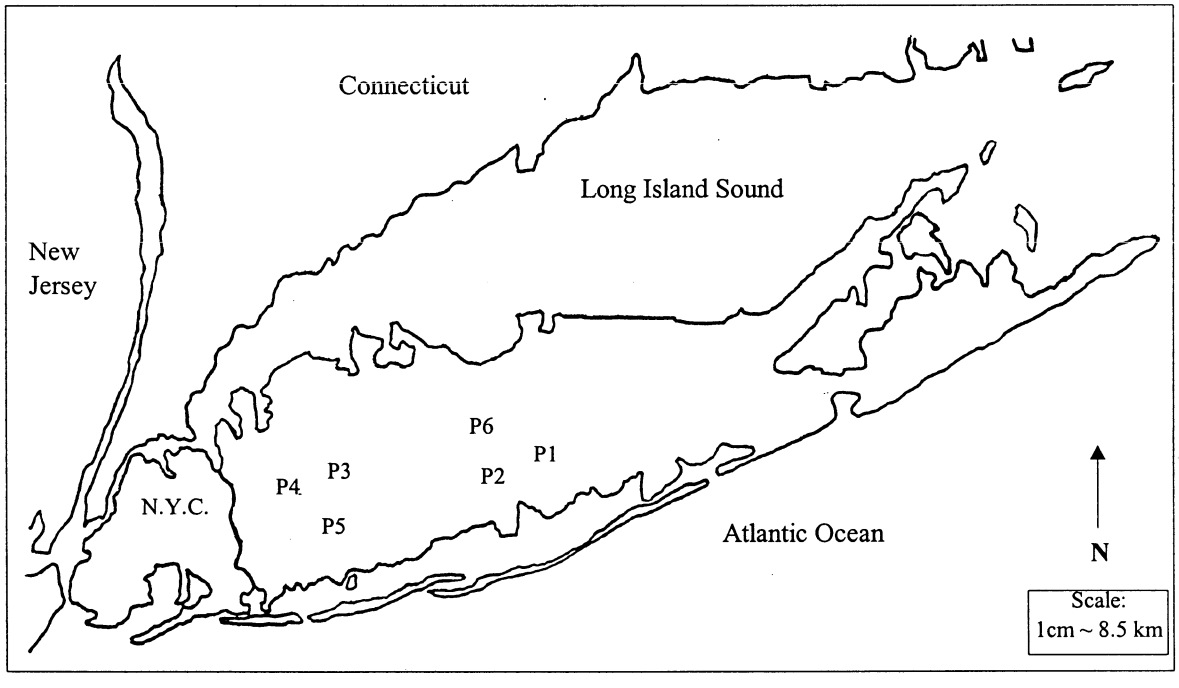
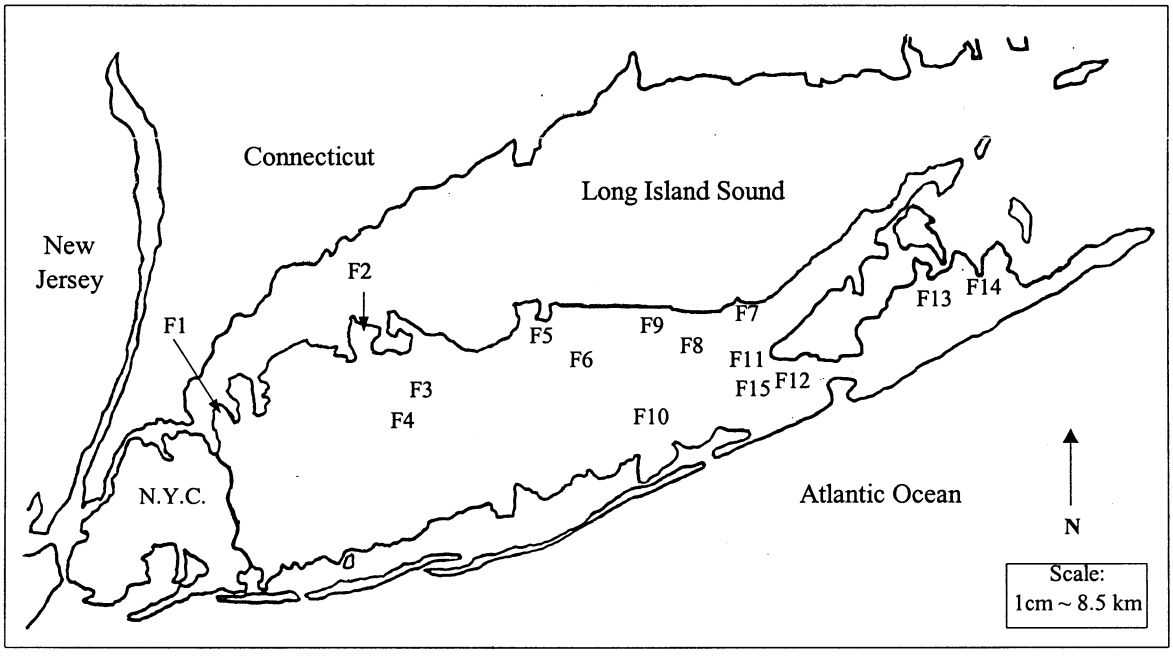


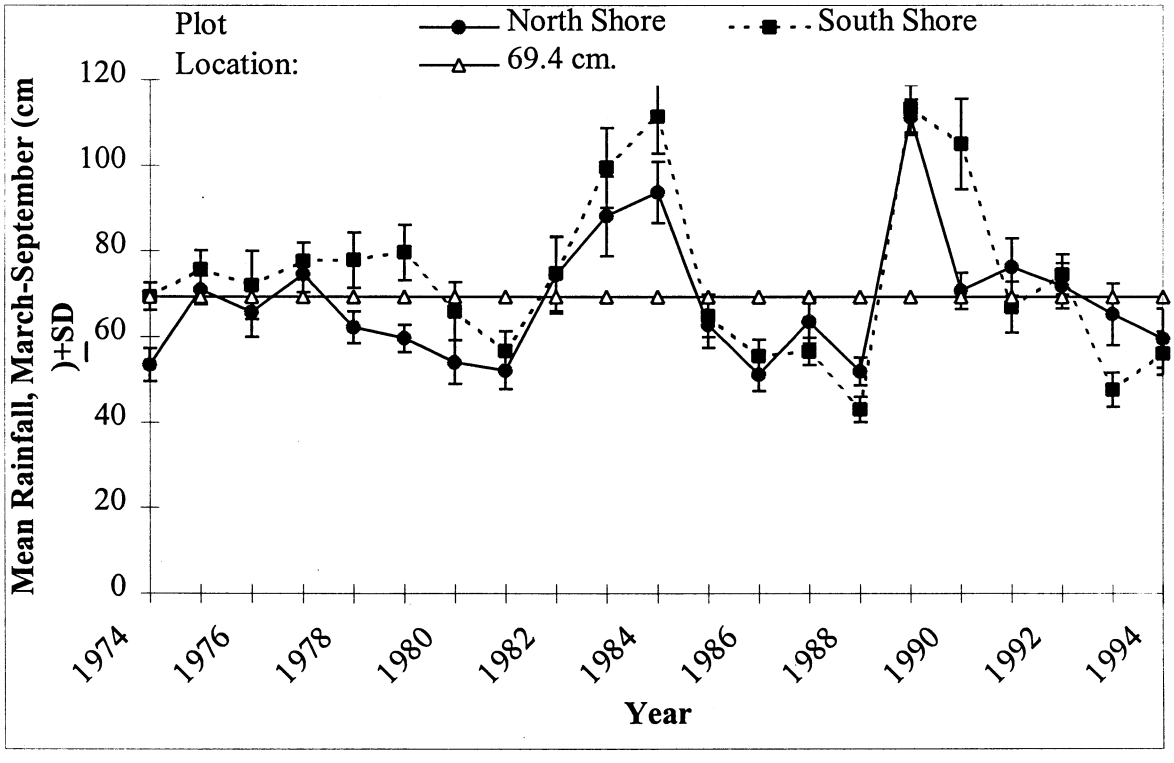
A-FIGURE 1. Approximate location of residential area plots surveyed in 1994. Ten trees were surveyed at each location.



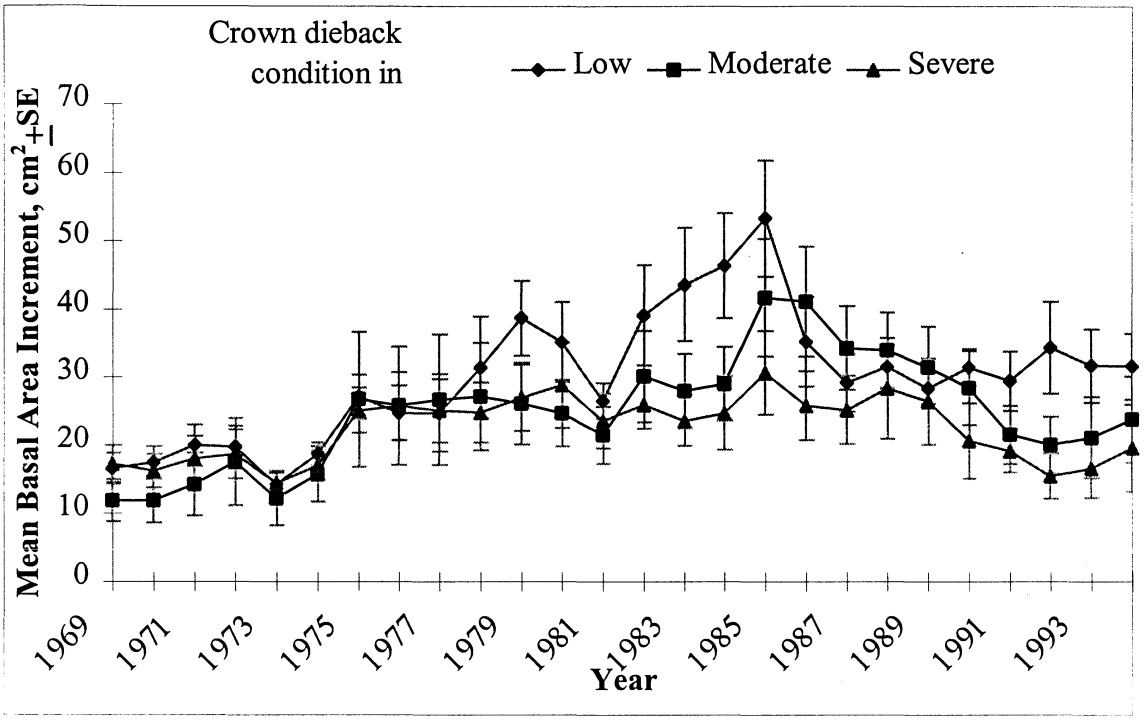
A-FIGURE 2. Approximate location of urban park plots surveyed in 1994. N=10 at each plot.



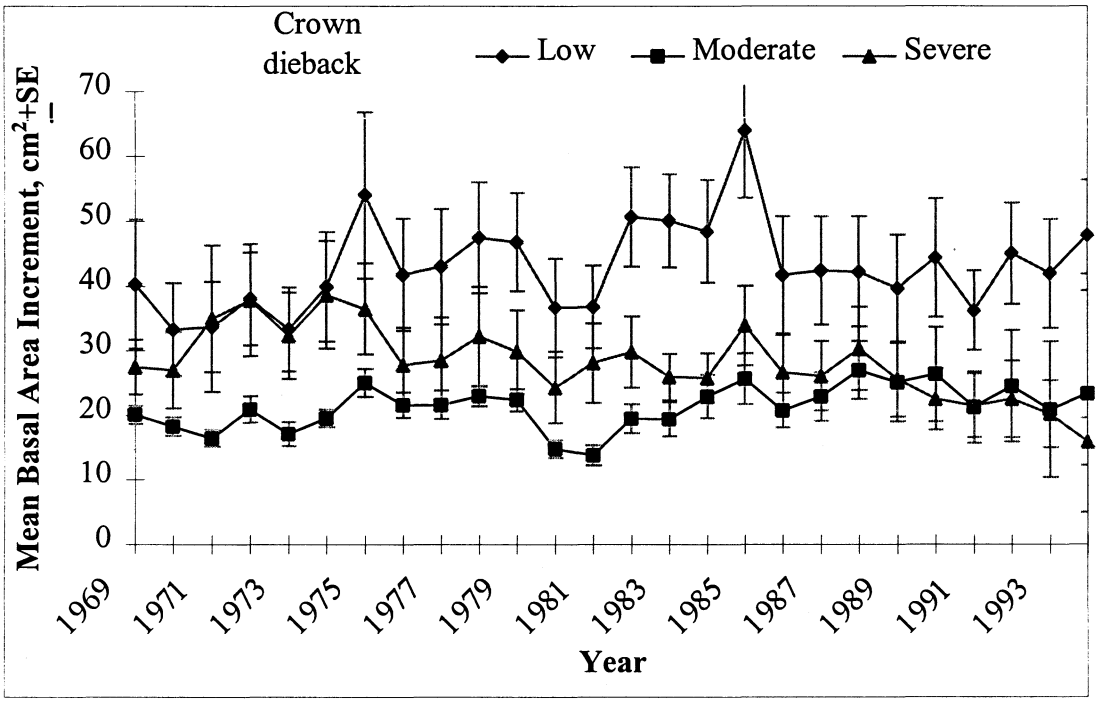
A-FIGURE 3. Approximate location of forested area plots surveyed in 1994. The number of trees surveyed at each location varied.



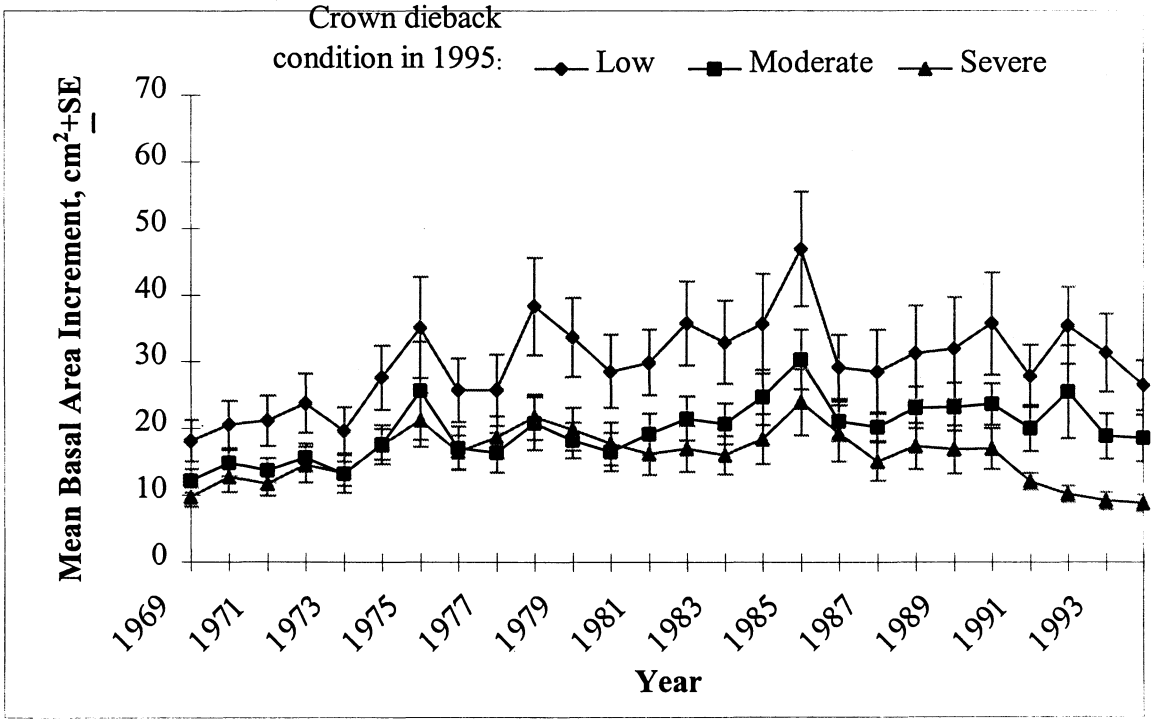
A-Figure 4. Mean annual rainfall for North and South Shore plots from 1974-1994.



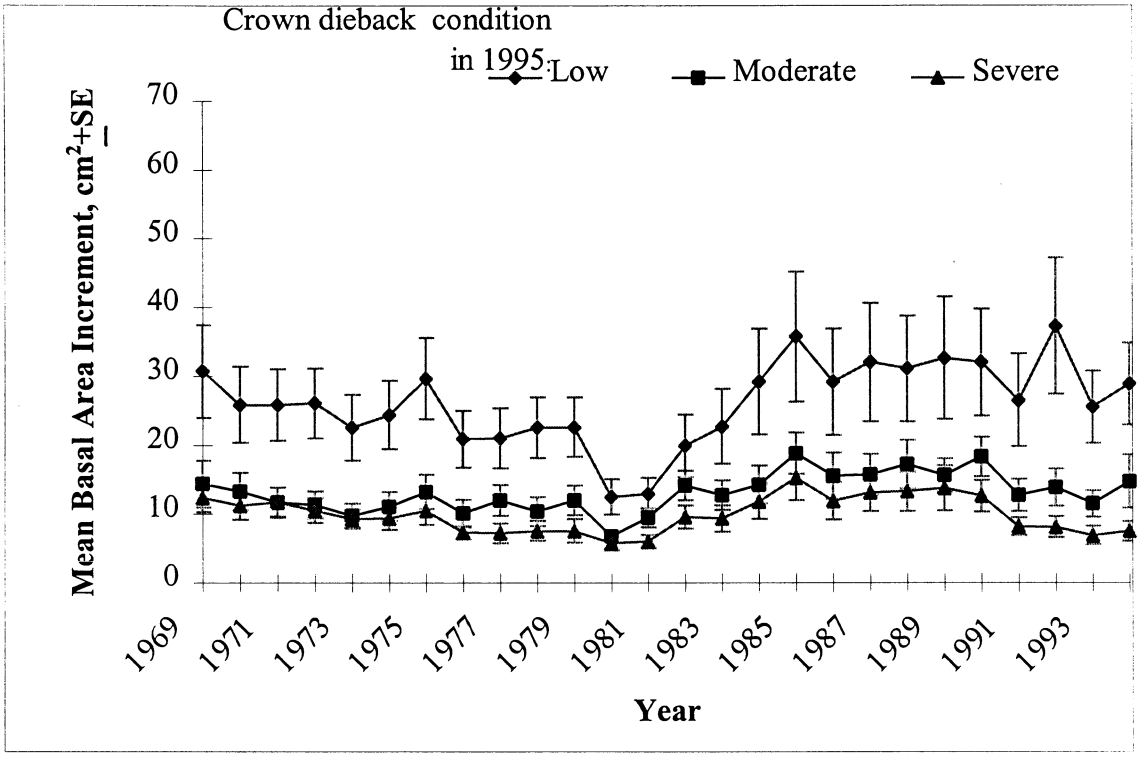
A-Figure 5. Mean annual radial increment for trees in a North Shore residential area.



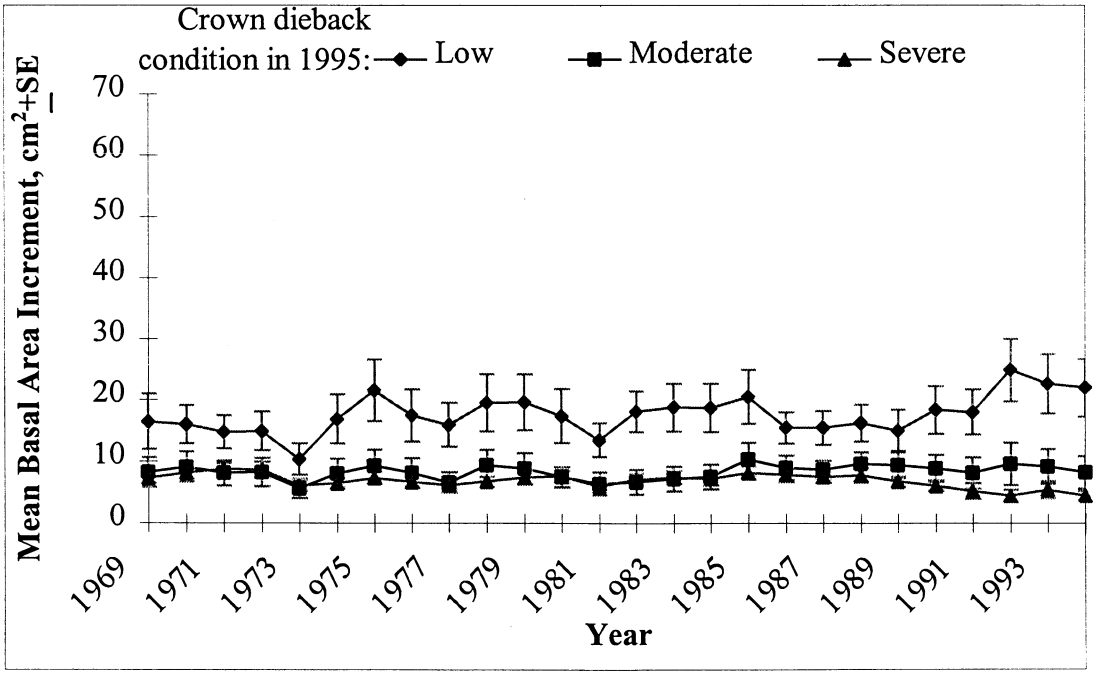
A-Figure 6. Mean annual radial increment for trees in a South Shore residential area.



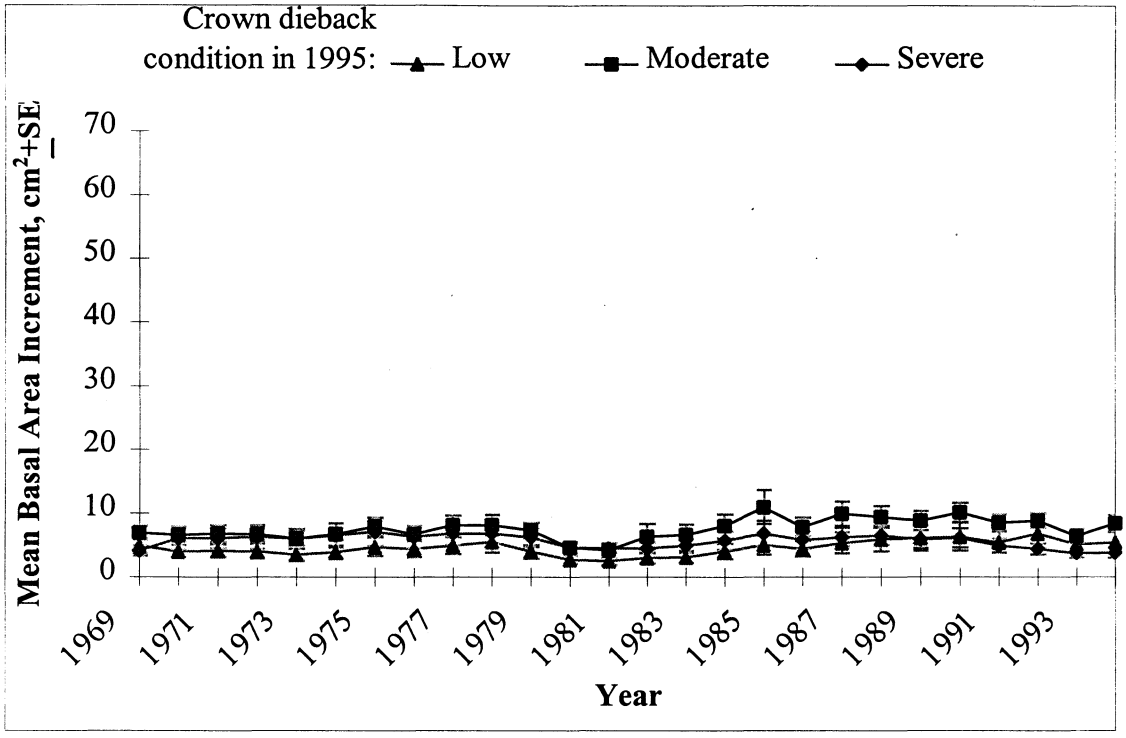
A-Figure 7. Mean annual radial increment for trees in a North Shore urban park.



A-Figure 8. Mean annual increment for trees in a South Shore urban park.



A-Figure 9. Mean annual radial increment for trees in a North Shore forested area.



A-Figure 10. Mean annual radial increment for trees in a South Shore forested area.

A-Table 1. Description of major soil series in Suffolk County. Eighty-two % of Suffolk county's soil series are represented. Soil descriptions are taken from Suffolk County Soil Survey (Warner et al.1975).

Soil Series	% Area	Parent material	Solum Thickness	Solum Texture	Moisture Capacity	Drainage	Restrictions
Carver	17	Thick glacial outwash deposit of medium and coarse-textured sand	16-32"	Med.& coarse sand	LOW	Excessively drained	-
Plymouth	15	Moderately thick outwash-sand-deposit over sand and gravel	20-36"	loamy sand	LOW-V. LOW	Excessively drained	-
Riverhead	31	Moderately thick deposit of sand, silt, clay over outwash sand	22-36"	loamy sand	HI-MOD	Well drained	-
Haven	13	Moderately thick deposit of silt and v.f. sand over sand & gravel outwash	18-36"	loam	HI-MOD	Well drained	-
Montauk	4	Morainic til deposit of sand and granitic material	23-40"	sandy loam	HI-MOD	Well drained	Fragipan
Bridgehampton	2	Thick silt deposit over sand and gravel outwash	36-56"	silt loam	HI	Well-moderately well drained	-

A-Table 2. Geographic locations for all 1994 survey plots.

Plot No.	Residential Areas	Plot No.	Forested Areas	Plot No.	Urban Parks
S1	Baldwin	F1	Sands Point County Preserve	P1	Bayard Cutting Arboretum
S2	South Hempstead	F2	Caumsett State Park	P2	Heckscher State Park
S3	East Hills	F3	West Hills County Park	P3	Bethpage State Park
S4	Glen Cove	F4	Woodbourne Nursery	P4	Eisenhower County Park
S5	Centerport	F5	Sunken Meadow State Park	P5	Hempstead Lake State Park
S6	Half Hollow Hills	F6	Caleb Smith State Park Preserve	P6	Connetquot River State Park Preserve
S7	Lindenhurst	F7	Wildwood State Park		
S8	Oakdale	F8	Brookhaven State Park		
S9	Lake Grove	F9	N.Y.S. Conservation Area		
S10	Old Fields		at Rocky Point		
S11	Shoreham	F10	South Haven County Park		
S12	Shirley	F11	Hubbard Brook County Park		
S13	Mastic Beach	F12	Sarnoff County Preserve		
S14	Westhampton	F13	N.Y.S. Conservation Area		
S15	Riverhead		at Barcelona Neck		
S16	Greenport	F14	Cedar Point County Park		
S17	Shelter Island	F15	Sears-Bellows Pond County Park		
S18	Montauk				
S19	Napeague				
S20	East Hampton				
S21	Southampton				

A-Table 3. Percentages of trees with bole damage, bark beetles, epicormic branching and large leaves.

Damage Category	Ecotype		
	Residential Area	Urban Park	Forested Area
Basal injury	12	22	17
Weather damage	12	18	19
Bark beetles	0	0	0
Epicormic branching	77	97	91
Large leaves	60	57	43
Crown Position:			
Codominant	82	85	68
Open Grown	15	15	1
Suppressed	3	0	31

A-Table 4. Total basal area (m^2) by tree species in forested area plots surveyed in 1994.

Plot Number	Tree Species												
	Black Oak	Other Oak[a]	White Oak[b]	Sassa-frass[c]	Dog-wood[d]	Pine[e]	Maple[f]	Hickory[g]	Birch[h]	Cherry[i]	Cedar[j]	Tulip[k]	Beech[l]
F1	42.90			1.32	0.74		2.25	2.29	0.52	0.62			
F2	22.45	27.30		0.24	0.79		1.04		6.60			16.40	8.50
F3	2.80	2.70	10.20	2.90	0.75		1.50	0.49	1.60				
F4	5.36	5.36	6.90	0.68	0.39			5.80		0.75			
F5	2.37	0.53		0.46			4.00	1.40	2.60	1.40	1.30		
F6	3.83	7.83	0.42		0.47	10.50	1.60			3.16	1.08		
F7	10.10		0.94	2.30	1.00		4.90	5.70					
F8		2.40				6.30							
F9	3.50	2.60	2.18		0.53	2.60		0.25					
F10	0.80	1.10											
F11	40.30	4.70				5.60							
F12	3.50	1.90	0.89			2.70							
F13	5.84	3.56	2.59	1.39	0.44			1.48					
F14	2.50	3.20	0.68	1.80									
F15	0.51	0.53				3.70							

[a] *Quercus rubra L.*, *Q. coccinea*, *Q. palustris* Muenchh.

[b] *Quercus alba* L.

[c] *Sassafras albidum* (Nutt.) Nees

[d] *Cornus* sp.

[e] *Pinus* sp.

[f] *Acer s* p.

[g] *Carya* sp.

[h] *Betula* sp.

[i] *Prunus* sp.

[j] *Juniperus* sp.

[k] *Liriodendron tulipifera* L.

[l] *Fagus grandifolia* Ehrh.

A-Table 5. Total basal area and number of stems for each forested ar plot surveyed in 1994.

Plot No.	No. stems	Total Basal Area (m^2)	Basal Area per hectare (m^2)
F1	40	133.92	1116.00
F2	29	138.55	1154.58
F3	73	169.16	1409.67
F4	44	208.69	1739.08
F5	66	259.01	2158.42
F6	63	89.34	744.50
F7	39	439.49	3662.42
F8	61	257.05	2142.08
F9	116	234.09	975.38
F10	87	175.91	1465.92
F11	33	137.47	1145.58
F12	62	146.89	1224.08
F13	63	162.16	2027.00
F14	50	128.22	1068.50
F15	56	128.8	1073.33

A-Table 6. Mean ±SD characteristics for trees in residential areas by plot. Plot locations are listed in A-Figure 1. Means within a column followed by different letters are significantly ($p<0.05$) different separated by Tukey's H.S.D. Method. N=10 for each plot.

Residential Plot	Tree Height (m)			Tree Diameter (cm)			% Crown Dieback			% Twig Galling			%Twig Cankering		
S4	**21.9**	± **3.6**	**a**	71.9	± 14.5	ab	14	± 14	bc	43	± 24	abcd	10	± 10	cd
S3	20.8	± 2.3	ab	72.6	± 8.6	ab	13	± 13	bc	49	± 23	abcd	13	± 19	cd
S11	19.4	± 3.1	abc	57.4	± 17.5	abc	11	± 5	c	35	± 23	cd	11	± 12	cd
S6	19.1	± 4.4	abcd	55.6	± 17.0	abc	11	± 5	bc	61	± 21	abcd	21	± 19	bcd
S5	19.1	± 4.2	abcd	57.4	± 15.0	abc	16	± 6	bc	84	± 24	ab	41	± 27	abc
S17	18.1	± 4.4	abcde	58.2	± 17.3	abc	21	± 26	bc	74	± 31	abc	28	± 24	abcd
S10	18.1	± 4.5	bcde	54.9	± 13.7	cd	14	± 20	bc	73	± 35	abc	35	± 23	abcd
S7	17.4	± 2.1	bcde	49.3	± 14.0	cde	24	± 23	bc	84	± 32	ab	50	± 29	ab
S2	16.9	± 2.2	bcde	**80.0**	± **19.8**	**a**	10	± 4	c	58	± 31	abcd	24	± 21	abcd
S8	16.8	± 1.6	bcde	50.5	± 11.4	cde	22	± 23	bc	81	± 19	abc	34	± 24	abcd
S9	15.8	± 2.7	cde	42.2	± 10.9	de	7	± 3	c	38	± 25	bcd	15	± 12	cd

Note: Bold indicates largest value in each column.

A-Table 7. Mean ±SD tree characteristics for urban parks by plot. Plot locations are shown in A-Figure 2. Means within a column followed by different letters are significantly different at $p < 0.05$, (Tukey's HSD Test for Unequal N). N=10 for all plots.

Urban Park Plot	Tree Height (m)	Tree Diameter (cm)	% Crown Dieback	% Twig Galling	%Twig Cankering
P3	**21.0 ± 2.4 a**	43.2 ± 15.2 b	23.0 ± 20 a	69 ± 24 a	**43 ± 22 a**
P1	18.3 ± 3.4 ab	**91.4 ± 10.2 a**	18.0 ± 15 a	81 ± 22 a	35 ± 22 a
P5	16.8 ± 0.3 ab	48.3 ± 15.2 b	17.5 ± 14 a	**86 ± 30 a**	40 ± 32 a
P2	16.8 ± 3.4 ab	45.7 ± 17.8 b	16.5 ± 11 a	75 ± 31 a	34 ± 26 a
P4	15.2 ± 1.8 b	50.8 ± 5.1 b	**30.0 ± 25 a**	84 ± 18 a	42 ± 24 a
P6	14.6 ± 3.0 b	35.6 ± 17.8 b	13.5 ± 6 a	78 ± 14 a	40 ± 32 a

Note: Bold indicates largest value in each column.

A-Table 8. Mean ±SD characteristics for trees in forested areas by plot. Plot locations are listed in A-Figure 3. Means within a column followed by different letters are significantly ($p<0.05$) different (separated by Tukey's H.S.D. Method).

Forested Area Plot	Tree Height (m)	[a] Tree Diameter (cm)	% Crown Dieback	% Twig Galling	%Twig Cankering	N
F2	**23.8 ± 2.1 a**	53.3 ± 12.7 ab	12 ± 4 a	47 ± 25 a	13 ± 16 a	6
F1	21.6 ± 1.5 ab	**73.7 ± 12.7 a**	10 ± 0 a	52 ± 28 a	24 ± 25 a	5
F7	20.1 ± 3.7 ab	35.6 ± 10.2 bc	11 ± 6 a	53 ± 39 a	17 ± 12 a	9
F4	17.7 ± 2.1 abc	25.4 ± 7.6 cd	20 ± 11 a	**66 ± 18 a**	44 ± 32 a	12
F11	17.1 ± 3.7 abcd	33.0 ± 7.6 bc	11 ± 3 a	21 ± 25 a	17 ± 2 a	8
F9	15.8 ± 6.7 bcd	20.3 ± 10.2 cd	24 ± 24 a	51 ± 32 a	28 ± 23 a	15
F6	14.3 ± 3.3 bcde	20.3 ± 10.2 cd	11 ± 3 a	40 ± 23 a	22 ± 23 a	10
F5	12.2 ± 4.9 cde	27.9 ± 5.1 de	25 ± 36 a	30 ± 27 a	15 ± 15 a	14
F13	12.2 ± 1.8 cde	17.8 ± 12.7 cd	15 ± 7 a	41 ± 34 a	37 ± 30 a	6
F3	11.9 ± 4.0 cde	16.0 ± 10.2 de	**37 ± 35 a**	32 ± 37 a	20 ± 21 a	9
F8	11.0 ± 2.7 cde	12.7 ± 5.1 de	10 ± 0 a	13 ± 15 a	**47 ± 17 a**	9
F14	10.7 ± 6.4 cde	15.2 ± 7.6 de	24 ± 28 a	8 ± 13 a	20 ± 19 a	4
F12	10.4 ± 4.3 de	12.7 ± 5.1 de	31 ± 31 a	24 ± 33 a	17 ± 15 a	8
F10	9.7 ± 2.1 e	10.2 ± 2.5 e	27 ± 22 a	10 ± 14 a	25 ± 18 a	12

Note: Bold indicates largest value in each column.

[a] Tree diameters were square root-transformed.

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Carolyn Pike, Daniel Robison and Lawrence Abrahamson

DRAFT

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Black Oak Decline on New York's Long Island, 1990-1996

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Summary

Decline of black oak, *Quercus velutina* Lamarck, on New York's Long Island in the early 1990's was found to be associated with two Cynipid gall wasps and a fungal twig canker. Symptoms included swollen twigs, gnarled branches, crown dieback and fungal cankers. A study conducted during 1994-1996 showed that the symptoms occurred in residential areas, managed parks and forested areas and in all sizes and ages of black oak. The severity of the decline varied greatly across Long Island. The fact that unaffected oaks were found next to declining oaks suggests a genetic basis for susceptibility to the decline. Trees that grew more rapidly before the gall wasp outbreak did not "dieback" as significantly as those that grew more slowly before the outbreak. A series of periodic environmental stress factors such as drought, severe wind, and defoliation, probably played an important role in triggering dieback in susceptible trees. Future cycles of decline lasting 5-10 years are expected, but cannot be predicted. Management of this decline syndrome is best accomplished by maintaining tree health before and during periods of stress, and removing affected trees that pose a threat to lives and property.

Introduction

In the early 1990's residents and arborists on New York's Long Island began reporting the deteriorating health of black oak, *Quercus velutina* Lamarck. Symptoms included thinning crowns, swollen twigs, twig cankers, tip dieback, leaf galls, unusually large leaves, and epicormic branches (Figure 1). Initial investigations by Suffolk County and Cornell Cooperative Extension, New York State Department of Environmental Conservation, and members of the Long Island Arboricultural Association, with assistance of Cornell University, identified three organisms closely associated with the decline: two gall wasps belonging to the insect family Cynipidae, *Bassettia ceropteroides* and *Callirhytis* sp., and a fungal twig canker, *Botryosphaeria* sp. Little else was known about the biology, ecology, and management of this decline syndrome.

Figure 2. Declining black oaks have the following symptoms: (a) heavy galling (swollen area of the branch), (b) cankering (vertical seam), and (c) dieback (dead branch tips), as shown in the photo. (Photo by Carolyn Pike)

In 1994, a formal study of this syndrome was undertaken. This paper describes the three organisms, and summarizes the findings and recommendations.

Biology and Ecology of Black Oak and Its Decline

Black oak is native and common across Long Island. It is a deep-rooted species, often found on poor quality soils, such as the drought-prone sandy soils common on much of Long Island. Black oak trees can live as long as 250 years, attain a height of 60 feet or more and a diameter of 3 feet or more. In forested areas, oak reproduction is favored in ecosystems where the soil surface has been disturbed and the light is readily available for germination of acorns and the growth of seedlings. Under a dense overstory, natural regeneration is slow, and black oaks

may be outcompeted by other tree species. Black oak regeneration in some forested areas on Long Island is minimal due to shading, and in residential areas and managed parks other seedbed requirements are also unmet.

Gall Wasps

The gall wasps (nonstinging) found in the swollen twigs of affected black oaks are from the Cynipid family of the Hymenoptera (Figure 2). This family of insects generally has a complex life cycle, which sometimes includes two generations a year, one consisting of all females (asexual) the other consisting of males and females (sexual). The tiny insects spend most of their lives as larvae (the immature maggot-like life stage) in cavities that they induce in the twigs. Larvae develop from eggs laid in and on twigs by adult wasps in spring.

Figure 2. Basettia ceropterides was one of two species of Cynipid wasps removed from black oak twigs. Approximate size is 3 mm (1/8 inch). (Photo by Carolyn Pike)

The majority of insects studied were *B. ceropteroides*, a species that has not been thoroughly studied. Its life cycle appears to occur in the following sequence. In the early spring, possibly before leaves have unfolded completely, a female gall wasp lays eggs on new twig growth. Each larva begins feeding into the twig and eventually forms a fully enclosed gall chamber. The larva obtains all of its nutrients from the inner surface of the chamber. Within this chamber, the insect passes through the pupal stage into the adult wasp, a process taking a few weeks. The wasp then chews through the gall chamber and the twig, emerging onto the twig surface. A larva that dies prematurely remains entombed within the twig. New wood forms around an empty gall after an adult emerges or around a gall containing a dead insect. This new growth forms the characteristic swollen twigs associated with this decline. The swellings may enlarge as the tree grows and persist for many years.

Since only female *B. ceropteroides* have been observed in twig galls, this insect is believed to represent the asexual generation. We have not observed activities of the adult asexual female after emergence. She may oviposit on another twig, leaf, or acorn of black oak or another plant species, producing offspring comprised of males and females (the sexual generation). How and where this insect survives the winter months also are not known.

Gall wasp populations are regulated by the health and vigor of the host trees, natural enemies, and other environmental factors. Their outbreaks persist for a few years or just one season. When factors favoring gall wasps diminish, their populations drop to low, endemic levels, possibly surviving as their alternate generation, for many years until conditions again become favorable.

Gall wasps have not received the notoriety of other forest pests because by themselves they generally do not compromise the health of trees. When large numbers of galls form in twigs on a single tree, disruption of water and nutrient flow within the tree's vascular system may produce tip dieback. This is probably the situation in the decline of black oak on Long Island.

Fungal Canker Disease

Botryosphaeria sp. is a fungal canker disease common on oaks. It generally occurs on the twigs of stressed trees, and is most often considered an opportunistic disease—one that requires a damaged or stressed tree to successfully establish itself. Trees that are stressed by gall wasps or other insects may be more susceptible to infection by *Botryosphaeria;* however, no direct association between *Botryosphaeria* and gall wasps has been made. Other abiotic factors, such as drought stress, are known to affect the susceptibility of oaks to *Botryosphaeria* infection. While this fungus can cause significant damage to stressed trees, it is seldom a problem in healthy trees.

Study Methods

A survey of black oak trees was conducted across Long Island in 1994 to assess the extent and severity of decline symptoms. The survey included trees in three ecotypes: (1) residential areas, (2) managed parks, and (3) forested areas. Trees in residential areas were those located along secondary and neighborhood streets and in yards of private residences. Tree management in these areas typically included regular watering or fertilization or both during the growing season, as well as potential stress from herbicide use, disturbed and compacted soil, runoff of pollutants

from road construction, and branch trimming. Trees in managed parks were located in picnic areas and campgrounds, and were exposed to pedestrian traffic, which may have caused soil compaction and displacement in places. In general, these trees were not watered or fertilized, management being limited to brush or understory removal in some areas. Trees in forested (natural) areas were located in county or state parks or preserves and were located at least 100 feet from a pedestrian trail. Trees in these areas were not actively managed.

For each tree surveyed, the height and diameter were measured and the severity of decline symptoms, including crown dieback and relative amounts of branch galls and branch cankers, were estimated.

Two areas with similar amounts of decline were studied more intensively in the summer of 1995. Terminal branch samples, 1 yard long, were taken from each of 180 trees located in the two areas and three ecotypes. Each branch was dissected to assess the number of galls, either empty or containing an entombed wasp, within each year of twig growth. These counts were used as estimates of the gall wasp population across recent time. To determine the growth rate of trees over time, an increment core containing a cross section of tree rings was obtained from the main stem of each tree. The widths of each growth ring were measured and basal area growth was estimated for each year.

Results and Discussion

During this study, the decline syndrome was evident throughout Long Island. Since symptoms were observed in forested areas as well as in residential areas, direct human impacts appeared unlikely to be important in influencing decline severity. Symptoms were not uniformly severe across the Island however, suggesting that certain microsite characteristics contributed to the decline. Percent crown dieback among residential trees was particularly high along the south shore of Long Island, moderate along the north shore, and intermediate throughout the interior and eastern south fork (Figure 3). These zones of low, moderate, and severe decline are correlated with the major soil associations on Long Island, but no cause-and-effect relationship between particular soil properties and the decline syndrome was found.

The syndrome was confined to black oak trees. While galls, cankers, and dieback were observed on other species of oaks, the particular combination of these factors and associated symptoms were found only on black oak. All size and age classes of black oak were affected. The extent of the decline varied greatly within a given area. Some oaks were severely affected (Figure 4a), while others, sometimes directly adjacent

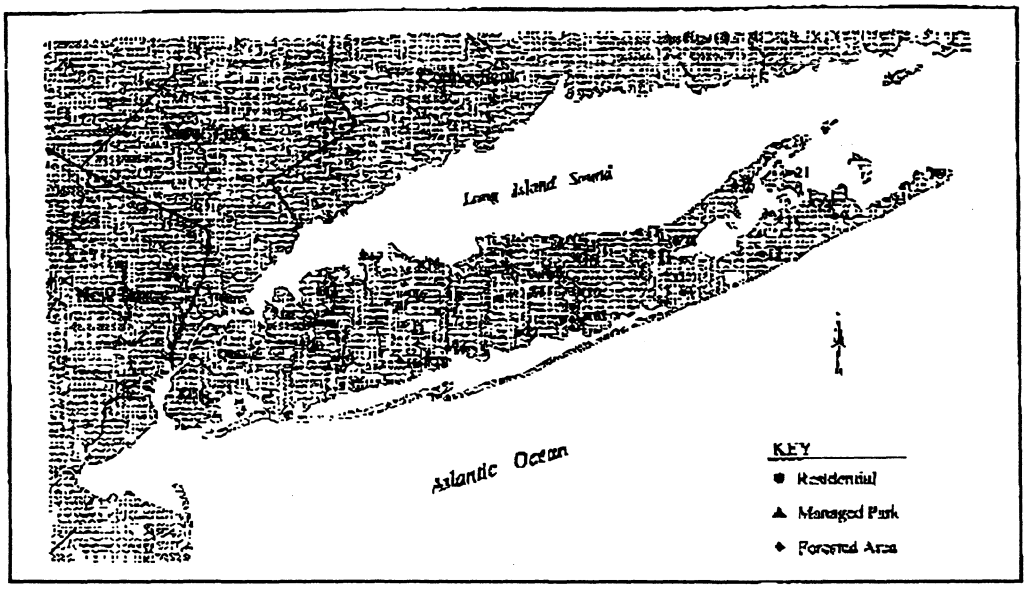

Figure 3. Average percent crown dieback for each survey plot in all ecotypes on Long Island, New York.

Figure 4a. Extensive crown dieback indicates advanced black oak decline. (Photo by Carolyn Pike)

to declining trees, showed little or no signs of decline (Figure 4b). These findings suggest that susceptibility to decline is governed by site factors or genetic predisposition or both.

Tree age, size, dieback severity, and tree location were not meaningfully correlated. Analysis of tree growth rates from increment cores (Figure 5), however, indicated that trees with the heaviest dieback in 1995 also had reduced growth before 1980 or before the onset of visible decline. Growth of declining trees in residential areas slowed from 1988 to 1995, and these trees apparently were predisposed to decline well before the gall wasp outbreak in the early 1990's. The growth trend for trees in managed parks was similar to those in residential areas. Incremental

Figure 4b. Trees with only slight crown dieback appear healthy.

growth of trees was, on average, two times greater in residential areas and managed parks than trees in forested areas. This difference reflects the greater intensity of inter-tree competition in forested areas, and the supplemental water and fertilizers that trees in residential areas and managed parks often receive. In general, decline symptoms were less severe in forested areas than in more urban areas.

As indicated by twig dissections, the number of gall wasps fluctuated more in residential areas than in forested natural areas. In residential areas, wasp numbers substantially increased in 1991 and sharply dropped in 1994 (Figure 6a). The trend was similar in managed parks. By contrast, in forested areas, wasp numbers gradually declined from 1990 to 1995 (Figure 6b). This pattern has been observed previously, leading

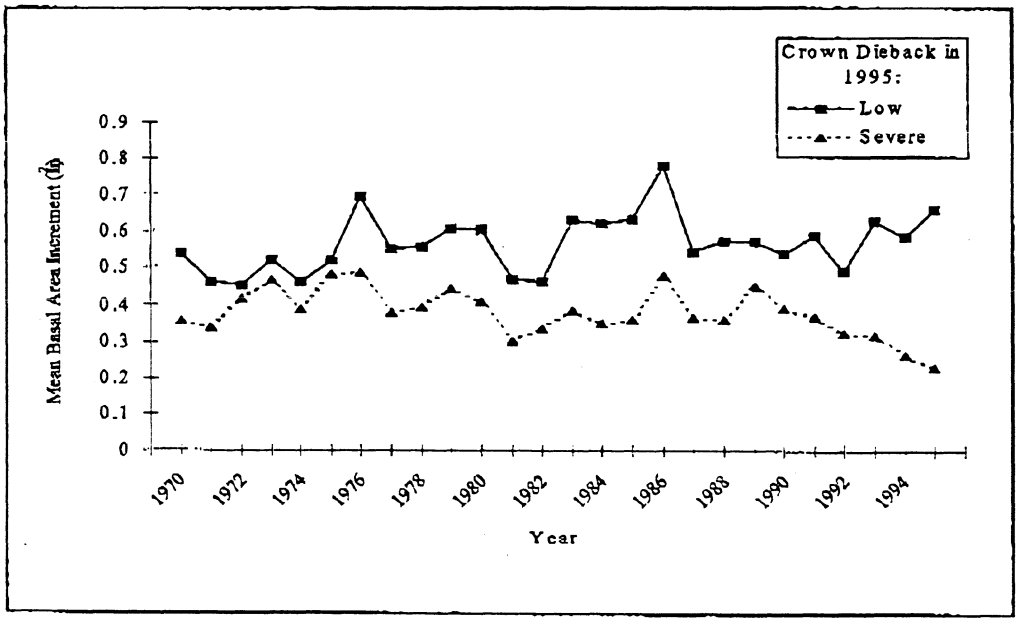

Figure 5. As shown by increment core analysis, average radial growth of black oak trees in residential areas of Long Island, gradually decreased in trees affected by black oak decline syndrome (those with severe crown dieback in 1995 and gradually increased trees unaffected by the syndrome (those with low crown dieback), from 1988 to 1994. For many declining trees, on average, grew more slowly than trees that appear healthy.

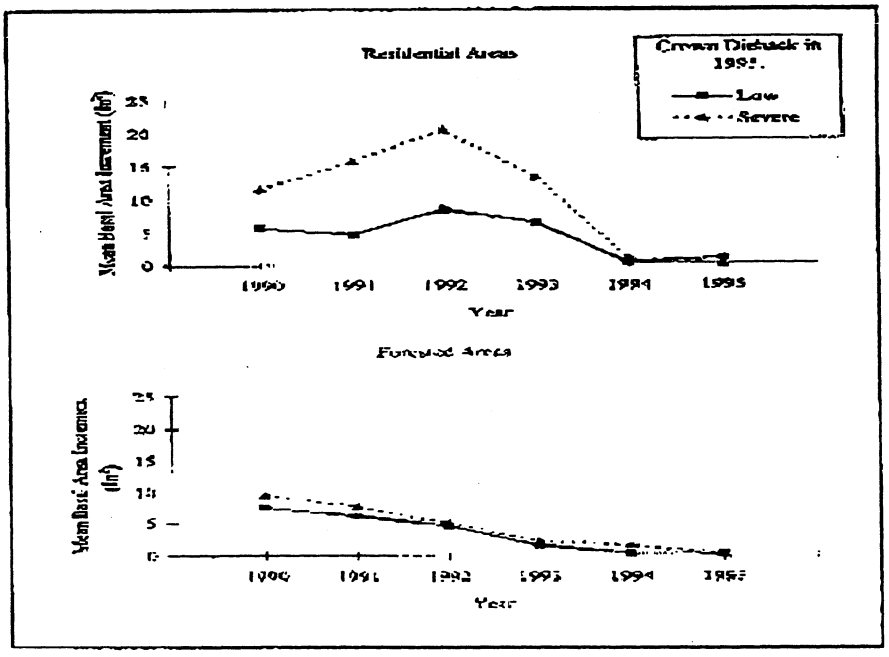

Figure 6. The average number of gall wasps excised from each year's growth of black oak on Long Island (a) decreased gradually in forested areas but (b) sharply increased then decreased in residential area from 1990-1995.

researchers to postulate the following about residential areas compared with forested areas: wasps are isolated from natural enemies for a longer period of time in residential areas; gall wasps are more successful because the trees are more vigorous, thus providing a better host environment; and dieback is usually more visible leading to the assumption that residential areas are more affected.

Probable Cycle of the Decline Syndrome

Black oaks from 27 to 133 years old were susceptible to the decline. Middle-aged trees are the most sensitive to stress because they lack the resilience of younger trees and have not "stood the test of time," as older trees have. Age was not, however, a reliable indicator of tree susceptibility in this study.

The combined effects of site factors, gypsy moth defoliation (early 1980's) drought (late 1980's) and frequent severe wind storms probably reduced the vigor of some trees, leading to dieback after gall wasp attack. Although all trees were infested by gall wasps, trees that grew slowly before gall wasp attack showed the most pronounced symptoms.

Since all trees were affected to some degree, it is difficult to determine how the gall wasp population spread. Did it originate from a single locale on the Island or did a region-wide occurrence trigger the emergence of many insects simultaneously? Surveys did not find the wasp in New York City, coastal or northeastern areas of New Jersey, or coastal Connecticut. Therefore, some unique condition in central and eastern Long Island is likely to be responsible for predisposing trees to dieback and decline, and for prompting the gall wasp outbreak.

During the 1960's similar decline symptoms, including twig galls and crown dieback, were reported on few Long Island trees. Research indicates that gall wasp outbreaks occur sporadically or cyclically, with populations and damage rising and falling in tune with some set of natural factors. This was probably the case on Long Island for the decline syndrome of the 1990's. All evidence indicates that the syndrome is no longer active on Long Island (as of the summer of 1997), or is confined to small, localized pockets. The health of the remaining black oaks on the Island is probably good, considering that the weakest trees were removed by the syndrome and subsequent cutting. The number of young black oaks in forested areas may have decreased, however, and regeneration may be poor and may lead to a subtle change in species composition. In residential areas and managed parks, the number of black oaks decreased as well.

Based on these findings, Long Island's black oak decline syndrome appeared in the late 1980's, and by 1996 had diminished across the Island. This cycle is not unexpected in nature. Another cycle of black oak decline associated with gall wasps or another organism may emerge in the future and follow a similar pattern of damage and recovery.

Management Recommendations

Arborists and others involved with the care and management of trees on Long Island responded in various ways to the syndrome, and to requests for help from their clients—private and public property owners and managers. Practitioners tried intensive irrigation and fertilization, insecticidal sprays and injections, soil aeration, and removing galls by pruning. In some cases trees were cut and removed, either because they appeared to pose a threat to public safety or property, or because they had become unsightly or had died. While some operators reported occasional success at improving tree health, no evidence exists to support the use of these actions to control or manage this syndrome or the associated insects and disease. As often as not, trees may have recovered without treatments the syndrome diminished naturally. Healthy trees with vigorous growth were less susceptible to decline.

Therefore, maintaining tree vigor may be the best management strategy. Loss of tree vigor before dieback appears is the best predictor of decline.

Galling insects generally are well protected from insecticidal sprays and tree injections. In fact, the gall consists of modified tree cells that protect the insects inside from toxic plant chemicals as well as from the external environment. Aerial application of insecticides might be effective if well-timed with the emergence and flight of adult wasps. Researchers at the University of Maryland, College Park, found that careful monitoring could identify the time of this adult wasp flight in spring. A spray protocol was not developed from data, because the disappearance of the syndrome and gall wasp populations by 1996 precluded controlled studies.

Integrated management of this decline syndrome is best accomplished through the maintenance of tree health and vigor and removal of affected trees when they pose a threat to human safety or to property. In parks and residential areas, planting diverse tree species will avoid wholesale loss of black oak when the next decline or pest episode develops.

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